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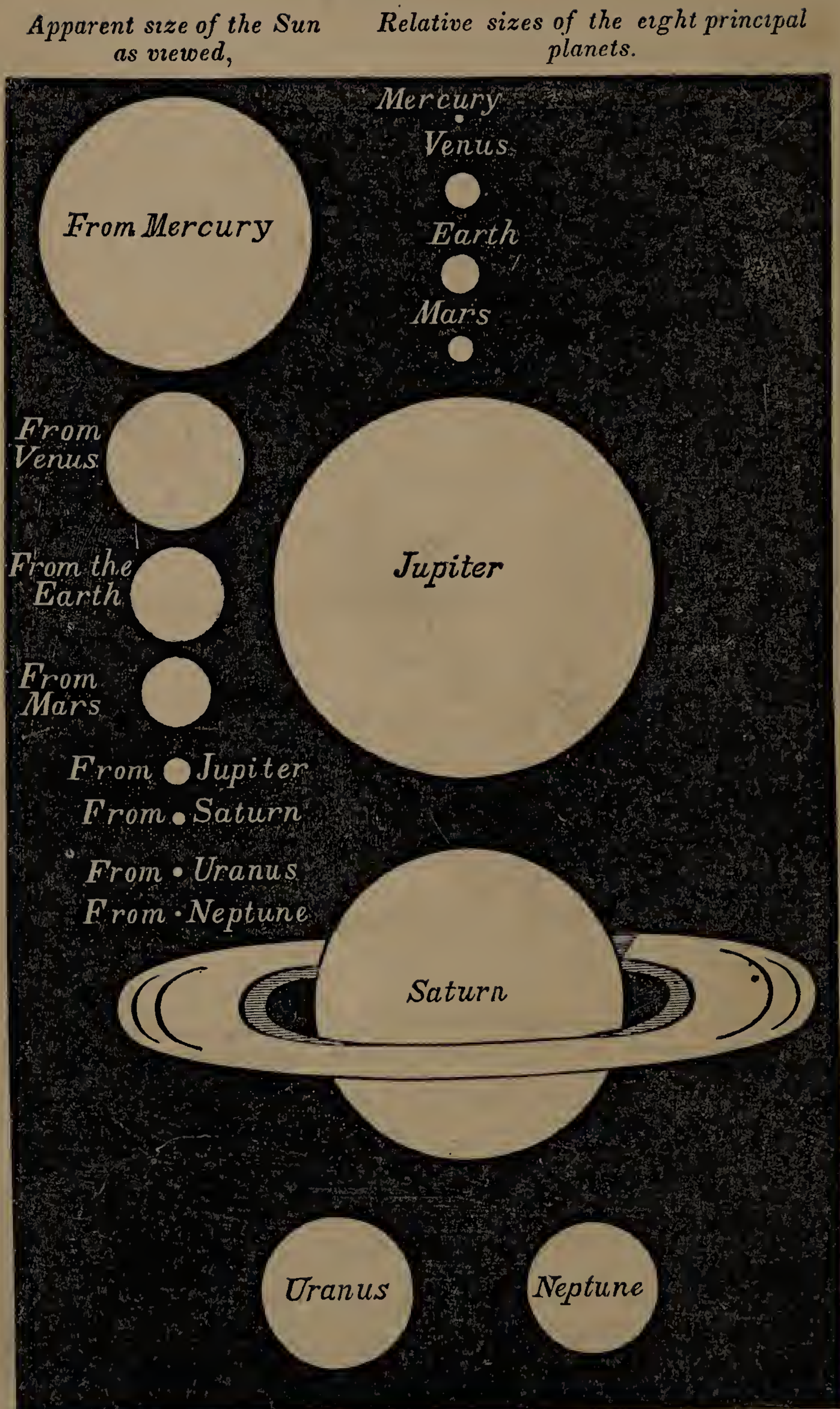

ELEMENTS

OF

ASTRONOMY,

FOR SCHOOLS AND ACADEMIES,

WITH

EXPLANATORY NOTES, AND QUESTIONS FOR EXAMINATION.

BY JOHN BROCKLESBY, A.M.,

PROFESSOR OF MATHEMATICS AND NATURAL PHILOSOPHY IN TRINITY COLLEGE, HARTFORD,
AND AUTHOR OF THE "ELEMENTS OF METEOROLOGY," AND OF THE
"VIEWS OF THE MICROSCOPIC WORLD."

Fully Illustrated.

"Lift up your eyes on high, and behold WHO has created these things, that bringeth out their host by number: HE calleth them all by names, by the greatness of HIS might, for that HE is strong in power; not one faileth."

A NEW EDITION, REVISED.

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PREFACE.

THE science of Astronomy, conversant as it is with the sublimest natural phenomena, has ever engaged the attention of mankind, even when, from century to century, scarcely any new revelation of the skies rewarded the labors of the astronomer.

But at the present time, when discovery crowds upon discovery, and the whole field of astronomical research has been wonderfully enlarged, it has suddenly become invested with the charms and freshness of a *new science;* and all classes of society listen with wonder and delight to the recital of the lofty truths and amazing facts which it unfolds.

In attempting, therefore, with many honored names, to cause Astronomy to descend from the dignified seclusion of the observatory, that she may walk as a familiar guest amid the lesser temples of knowledge, no apology is required for the *motive* that prompts the task how much soever it may be needed on account of the *execution.*

In the present treatise the author has not sought to adapt its subject to the youthful mind, by curtailing the science of its fair proportions, and omitting every thing that requires *patient* and *earnest* study; but he has aimed to preserve its great principles and facts in their *integrity*, and so to *arrange*, *explain*, and *illustrate* them, that they may stand out boldly defined, and be clear and intelligible to the *honest* and *faithful student*,—this is all that can be done for a pupil, if a science is to be taught in its *completeness* and not *in parts.*

The *hill of science* will *always be a hill.* Impediments and obstructions may be removed and the ascent rendered easier, but the hill *cannot* be *leveled*, it must be *surmounted.*

Several peculiarities are contained in this text-book, which it is thought will be of material service to the pupil in obtaining a knowledge of the science. The most important of these we shall now briefly notice.

I. It is usual, in most text-books on this science, to explain many astronomical phenomena by the *apparent*, and not by the *real* motions of the celestial bodies. In this treatise the *opposite course is taken*, wherever practicable; the explanations being based upon the *real motions* of the heavenly bodies. By pursuing this method, the subsequent acquisitions of the scholar are built upon the *truth itself*, and not upon what *appears to be true.*

II. The *mode* of ascertaining the *distances* and *magnitudes* of the heavenly bodies is so simplified that any student, who understands the *rule of proportion*, can readily comprehend it.

III. *Scientific terms* and *expressions* are explained by foot notes on the pages in which they occur; and in these notes are likewise embodied such *illustrations* and *information* as tend to elucidate the text.

In the preparation of this manual, the author has had recourse to numerous standard works upon Astronomy, and has brought up the subject to the present time. For information respecting recent astronomical discoveries, he is especially indebted to the treatises of Sir John Herschel and Mr. J Russel Hind.

HARTFORD, Feb. 19th, 1855

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ASTRONOMY.

INTRODUCTORY CHAPTER.

1. ASTRONOMY is that branch of NATURAL SCIENCE which treats of the MAGNITUDES, DISTANCES, CONSTITUTIONS, and MOTIONS of the HEAVENLY BODIES, and the LAWS which regulate them.

2. THE HEAVENLY BODIES consist of *moons*, *planets*,[1] *comets*,[2] and *suns;* and possibly a fifth class exist called *nebulæ.*[3] To moons, planets, and suns the general name of *stars* is often given.

3. No heavenly body is independent of another. Each exists and moves as a part of one vast and harmonious combination, termed the UNIVERSE. The Visible Heavens are a portion of this Universe. How great or how small a portion we cannot say; for the rest, shrouded from our view in the depths of space, lies beyond the limits of our knowledge.

4. The mode of union existing among the heavenly bodies is the following: One or more moons *revolve*

1. *Planet*, from the Greek word *planëtes*, signifying a *wanderer*, a star that changes its place in the heavens.

2. *Comet*, from the Latin word *coma*, *a head of hair*, this body presenting a hairy appearance.

3. The name of *nebulæ* is given by astronomers to certain objects in the distant heavens which appear like small clouds, or specks of mist. True nebulæ are supposed to be vast collections of unformed matter, thinly diffused through space. Nebulæ is a Latin word, signifying *mists*, or *clouds.*

What is Astronomy? What do the heavenly bodies consist of? Does a heavenly body exist and move independent of others? What is said of the visible heavens? What is the mode of union between heavenly bodies?

about a planet; several planets with their attendant moons *revolve about a sun*, around which, likewise, sweeps a numerous train of comets. A sun with its assemblage of planets and comets constitutes a *system*.

5. The investigations of astronomers tend to prove that these systems are not fixed in space, but revolve like planets about some common central point, or body. And we have reason for believing that this mode of arrangement extends throughout all space, groups of systems rising one above the other in magnitude; the lesser forming a part of a greater, until at length their vast aggregate embraces and completes the Universe.

6. SOLAR SYSTEM. The sun with his train of planets, moons, and comets, forms the SOLAR SYSTEM.

The number of planets now (1863) known is *eighty-four.* Seventy-three of these have been discovered within the last eighteen years, and others will doubtless be detected. The names of the planets, with the symbols assigned them, are given in the following table, in the order of their distances from the sun, beginning with the nearest.

7. TABLE OF THE PLANETS.

SYMBOLS.	NAMES.	SYMBOLS.	NAMES.
☿	MERCURY, (nearest.)*	(21)	LUTETIA.
♀	VENUS.	(19)	FORTUNA.
⊕	EARTH	(11)	PARTHENOPE.
♂	MARS.	(17)	THETIS.
		(22)	CALLIOPE.
	ASTEROIDS.	(46)	HESTIA.
(71)	FERONIA.	(29)	AMPHITRITE.
(8)	FLORA.	(74)	GALATEA.
(43)	ARIADNE.	(13)	EGERIA.
(40)	HARMONIA.	(5)	ASTRÆA.
(18)	MELPOMENE.	(56)	MELETE.
(12)	VICTORIA, or CLIO.	(32)	POMONA.
(27)	EUTERPE.	(14)	IRENE.
(4)	VESTA.	(53)	CALYPSO.
(30)	URANIA.	(23)	THALIA.
(51)	NEMAUSA.	(37)	FIDES.
(9)	METIS.	(75)	(not named.)
(7)	IRIS.	(15)	EUNOMIA.
(60)	ECHO.	(50)	VIRGINIA.
(63)	AUSONIA.	(66)	MAJA.
(41)	DAPHNE.	(26)	PROSERPINE.
(25)	PHOCŒA.	(3)	JUNO.
(20)	MASSILIA.	(70)	PANOPŒA.
(67)	ASIA.	(64)	ANGELINA
(6)	HEBE.	(34)	CIRCE.
(44)	NYSA.	(58)	CONCORDIA.
(42)	ISIS.	(59)	OLYMPIA.

*See note, page 198.

SYMBOLS.	NAMES.
(68)	LETO.
(54)	ALEXANDRA.
(38)	LEDA.
(45)	EUGENIA.
(36)	ATALANTA.
(72)	NIOBE.
(1) ⚳	CERES.
(39)	LÆTITIA.
(2) ⚴	PALLAS.
(28)	BELLONA.
(55)	PANDORA.
(33)	POLYMNIA.
(47)	AGLAIA.
(16)	PSYCHE.
(35)	LEUCOTHEA.
(61)	DANAË.
(60)	HESPERIA.
(49)	PALES.
(52)	EUROPA.
(48)	DORIS.
(62)	ERATO.
(10)	HYGEIA.
(24)	THEMIS.
(31)	EUPHROSYNE.
(57)	MNEMOSYNE.
(65)	CYBELE.
(73)	CLYTIA. } Rank in order not yet ascertained.
(76)	FREYA. }
♃	JUPITER.
♄	SATURN.
♅	HERSCHEL, or URANUS.
♆	NEPTUNE, (most distant.)

8. All the planets between Mars and Jupiter are termed *Asteroids.*[1] In the annexed cut a view of the solar system is presented. The Roman numeral, I, represents the orbit[2] of Mercury; II, that of Venus; III, that of the Earth; IV, that of Mars; V, the orbit of the nearest asteroid; VI, that of the most remote asteroid; VII, is the orbit of Jupiter; VIII, of Saturn; IX, of Herschel; and X, of Neptune. In the cut the distances of the several planets from the sun bear the same relation to each other as their actual distances.

9. THE MODE OF CONDUCTING ASTRONOMICAL INVESTIGATIONS. When an artisan wishes to ascertain the dimensions of a stick of timber he does so by means of a rule, the length of which he *knows*, and thus he obtains the solidity of the log in feet and inches.

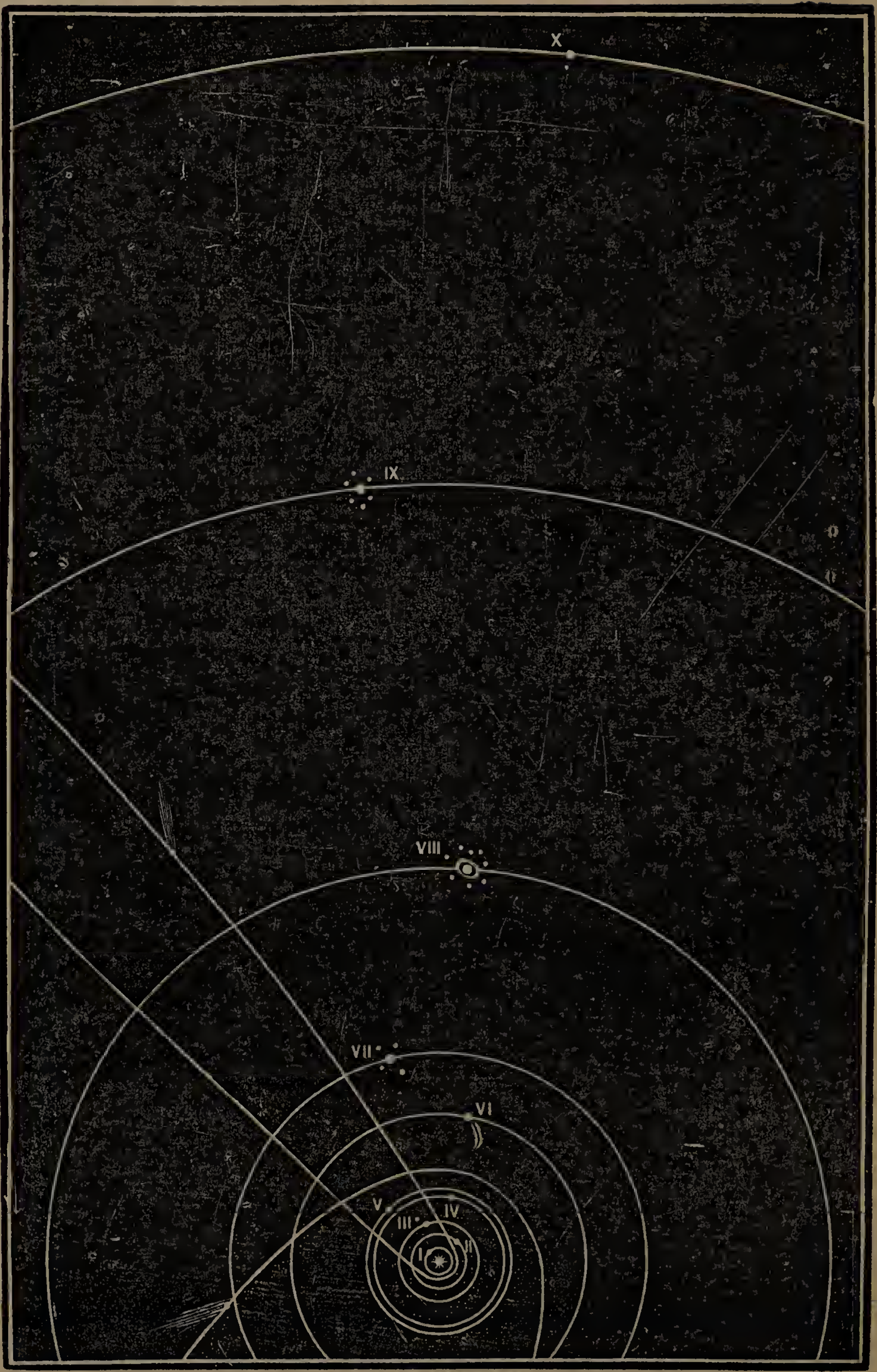
When, likewise, we wish to determine the speed of a locomotive, we measure by the aid of a watch the time taken to pass over a known number of miles. Thus *unknown* magnitudes and motions are ascertained by comparing them with such as are *known.*

In astronomical investigations we pursue a like course, and begin with determining the *size*, *motions*, and *form* of the EARTH, with other important particulars that are within our reach. We thus obtain *fixed standards* of

1. Asteroids. From two Greek words, aster, ***a star***, and eidos, ***like. Like a star***, because all these planets are very small.

2. Orbit means the path of a planet about the sun. So called from the Latin word, ***orbis***, ***a circle***, ***a circuit.***

What are the Asteroids, and where situated? Explain the figure. In what manner astronomical investigations conducted?



SOLAR SYSTEM.

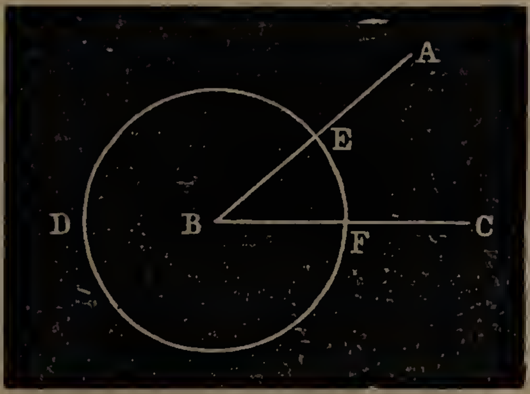
measurement, whereby we are enabled to push our inquiries beyond the earth, and to compute the distances, times, motions, and velocities of many of the bright orbs[1] that glitter about us, and the extent of the vast spaces through which they move. In the study of Astronomy our attention is, therefore, directed *First* to the EARTH in its relation to the rest of the heavenly bodies. *Secondly*, to the SOLAR SYSTEM. *Thirdly*, to the STARRY HEAVENS, of which this system is a part.

EXPLANATORY CHAPTER.

10. IN learning Astronomy it is necessary for the pupil at the outset to know the meaning of certain mathematical and philosophical terms and expressions, which are constantly occurring in the discussion of astronomical subjects. These must be mastered in order to obtain a clear understanding of the science, and yet they are by no means difficult to comprehend. The most important of these are explained in the present chapter. The meaning of other terms and phrases will be given as they occur in the book.

11. ANGLE. An angle is the *opening or inclination between two lines that meet each other;* thus, in Fig 2 the

FIG. 2.



AN ANGLE.

1. The stars are frequently called *orbs*, from their round figures. *Orbis*, (Latin,) *a circle*.

In what order are the subjects of astronomy to be studied? In learning astronomy what is it necessary for the pupil to do at the outset? What is an angle?

line AB meets the line BC, and the opening between them is called the *angle*, B, or the *angle*, ABC; the letter at the point of meeting, always being placed in the middle.

The size of an angle is computed as follows. The circumference of any circle being divided into 360 equal parts, each part is called a *degree;* a degree being divided into 60 equal parts, each part is called a *minute;* a minute being divided into 60 equal parts, each part is called a *second.* If, now, we take the point B, as the centre of a circle, and describe the circumference, DEF, cutting the two lines, AB and CB in any two points, as E and F, the *number of degrees, minutes, and seconds* contained in the part of the circumference, EF, included between the two lines, AB and CB, gives the *value of the angle*, ABC. For example, if the length of the circumference, DEF, was 360 *inches*, and the part, EF, contained 40 *inches and nine-sixtieths* ($40\frac{9}{60}$) of an inch, ABC would be an angle of *forty degrees and nine minutes* (40° 9′.) *Degrees* are denoted by the following character, °; *minutes* thus, ′; and *seconds* thus, ″.

12. A Right Angle. A right angle contains 90°, and can be thus constructed. Draw two diameters through any circle, dividing the circumference into *four equal parts*, and each of the angles at the centre will be a right angle, for since the whole circumference contains three hundred and sixty degrees, *one-fourth* of it con-

FIG. 3

RIGHT ANGLE.

How is its size computed? Describe from the figure. How are degrees, minutes, and seconds denoted? What is a right angle, and how is it constructed?

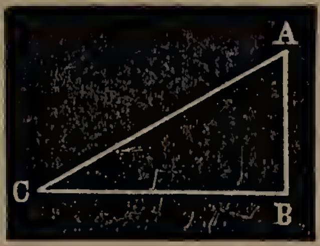
tains *ninety degrees.* Thus, in Fig. 3, the two diameters, AB and DE, dividing the circumference of the circle, A, D, B, E, into four equal parts, make each of the angles at the centre, right angles, viz., ACD, DCB, BCE, and ECA.

13. TRIANGLES. A triangle is a figure that is bounded by *three lines*, either curved or straight, and contains *three angles;* hence its name, derived in part from a Latin word,

FIG 4

A RECTILINEAR TRIANGLE.

FIG. 5



A RECTILINEAR RIGHT-ANGLED TRIANGLE.

tres, meaning *three.* The sum of the three angles of any rectilinear[1] triangle is always equal to 180°. Fig. 4 represents any such triangle, and the sum of its angles is equal to 180° A right-angled rectilinear triangle is one that contains one right angle. Thus, Fig. 5 is a right-angled triangle, since it contains a right angle, viz., ABC.

14. SIMILAR TRIANGLES. Similar triangles are those which have *all the angles of one triangle equal to those of*

FIG. 6.

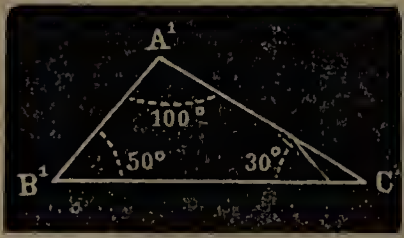
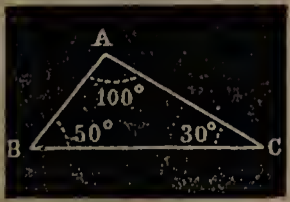


FIG 7.



SIMILAR TRIANGLES.

the other, each to each, and the sides forming the equal angles proportional; thus, in Figs. 6 and 7, the triangles,

1. Rectilinear, from rectus, *straight*, and linea, *a line*, (Latin,) STRAIGHT LINED.

What is a triangle? How many degrees does it contain? Refer to figure. What is a right-angled triangle? Refer to figure. What are similar triangles? Explain from figure.

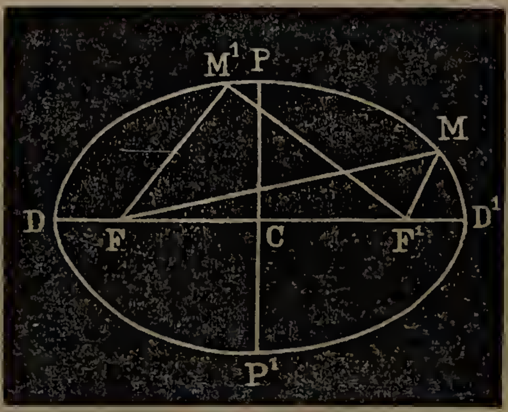
$A^1B^1C^1$ and ABC, are similar, because the angle B^1 equals B, A^1 equals A, C^1 equals C, and the side A^1B^1 · AB : : A^1C^1 : AC; and so of the other sides.

15. A Plane Surface. A plane surface is such that if any two points in the surface are connected by a straight line, every part of that straight line touches the surface. To illustrate. The surface of tranquil water in a pond is a plane surface, because if any two points on the surface are taken, and are connected by a perfectly straight rod, every part of the lower side of the rod touches the water. Such a surface is sometimes termed a *plane*. Thus, the surface of this page, when pressed flat, is a plane surface, or plane.

15[1]. A Plane Figure. A plane figure is one whose bounding line or lines are situated in the same plane. The flat cover of this book is a plane figure.

16. Ellipse. An ellipse is a plane figure, bounded by a curved line, and so constructed that if two straight lines are drawn from two points within, called the *foci*, to *any point* in the curve, the *sum* of *these lines* is invariably the same for the *same* ellipse. Thus, the annexed figure is an ellipse. F and F^1, the foci, and if

FIG. 8



AN ELLIPSE.

straight lines are drawn to any points, as M and M^1; FM added to F^1M equals FM^1 added to F^1M^1, and so of lines drawn to any other point. The line DD^1, drawn through the foci and terminated by the curve, is called

What is a plane surface? What a plane figure? What is an ellipse? Describe it from figure.

the *major axis* of the ellipse. The line PP^1, drawn through C, the middle of DD^1, or the centre of the figure, is the *conjugate axis*.

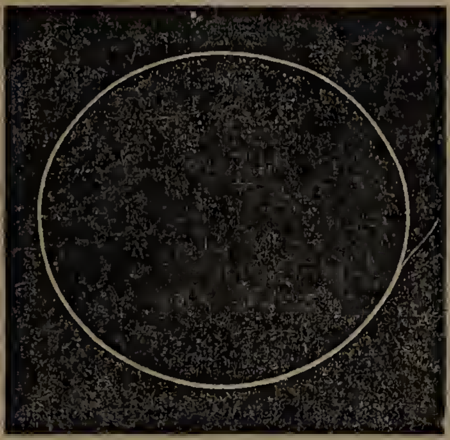
17. To Construct an Ellipse. Stick two pins into a piece of paper, at a short distance from each other, as at F and F^1, and pass over them a loop of thread, place a pencil in the loop, and keeping the thread tight, a triangle will be formed like FMF^1, the pencil being at M. Passing the pencil completely round F and F^1, its point will mark out an ellipse. For since in making the circuit, the length of the loop does not change, neither the distance between F and F^1, it necessarily follows that the sum of the distances from the pins to the pencil; viz., F^1M, FM, &c., is invariable.

18. Eccentricity. Ellipses differ among themselves. If the foci are near the centre of the ellipse, the ellipse approaches the form of a circle; but if the foci depart widely from it the length of the conjugate axis is small in proportion to that of the major axis, and the ellipse is said to be very eccentric.[1]

The distance from the centre to either focus; viz., FC, or F^1C, is termed the *eccentricity of the ellipse*. In

FIG 9

FIG. 10.



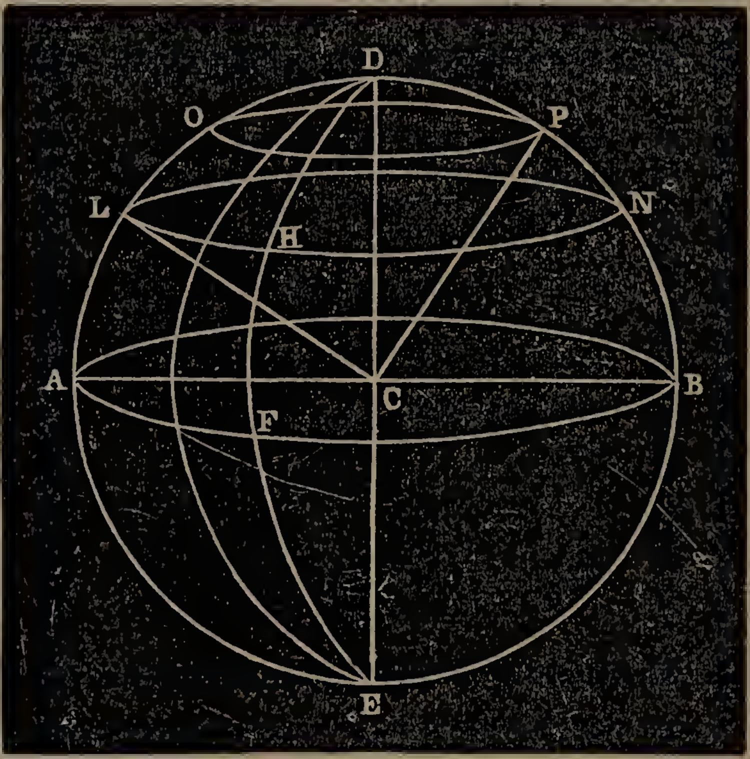
Figs. 9 and 10, two ellipses are exhibited which differ greatly in their eccentricity; one being almost a circle, and the other very oval.

1. *Eccentric*, from ex *out of*, and centrum *centre*, (Latin) *out of the centre.*

Construct an ellipse? What is meant by the term eccentricity?

19. A Sphere. A sphere is a solid, bounded by a curved surface, *every point of which is equally distant from a point within, called the centre;* every line passing through this centre, and limited by the surface, is a *diameter.* The half of this line is a *radius* of the

FIG. 11.



A SPHERE WITH ITS SECTIONS.

sphere. Thus in Fig. 11, representing a sphere, the points D, O, L, A, E, H, N, &c., are all equally distant from the centre C. DE and AB, are diameters, and CP, CL, CA, CB, &c., are each a radius.

If a plane passes through a sphere, any section it makes with the sphere is a circle. A *great circle* passes through the centre of the sphere, all other circles are small circles. Thus in the figure, AFB is a *great circle,* and LHN and OP *small circles.*

20. Poles of a Circle of a Sphere. The *poles* of a *circle of a sphere* are *points* on the *surface of a sphere, equally distant* from *every point in the circumference of that circle.* Thus, D is the pole of the circle LHN, because the curved lines DH, DN, and DOL, and all others

What is a sphere? Describe it from the figure with its *lines* and *sections*? What are the poles of a circle of a sphere? Explain from figure.

drawn to the circumference LHN, are equal to one another. For the same reason D is the pole of the circles OP and AB. It will also be seen that the point E is situated like D, with respect to these circles, since the curved lines EBN and EAL are equal, as likewise ELO and ENP. Each circle of a sphere has therefore *two poles.*

In a great circle the poles are each *ninety degrees* distant from the circumference of the circle, thus in the great circle AB, the poles E and D are each ninety degrees from its circumference, AFB.

2

PART FIRST.

THE EARTH IN ITS RELATION TO OTHER HEAVENLY BODIES.

CHAPTER I.

ITS FORM, SIZE, AND ROTATION.

21. ITS FORM. The earth appears to our view to be nothing more than a vast broken plain, rising into mountains, sinking into vallies, and spreading out into lakes, seas, and oceans; but a careful investigation re-

FIG. 12.

THE EARTH.

moves this erroneous impression and proves, *First* that the general surface of the earth is *curved;* *Secondly*, that the mass itself is *nearly spherical* in form; *Thirdly*, that it *rests upon nothing.*

22. These facts are established by several independent proofs. *In the first place* when a vessel sails from the shore the spectators upon the strand, as they watch her lessening in the distance, at length perceive the hull gradually sinking below the line of the horizon[1]; next

1. Horizon, a *boundary.* It here means the line that apparently divides

What does PART FIRST treat of? What does Chapter First treat of? What appearance does the earth present? What facts have been proved by careful investigation? State the several proofs of these facts?

the lower sails disappear, and the last objects that are seen are the tops of the masts, on a level with the distant waters; and this is the case in whatever direction the vessel sails. *Secondly*, navigators have repeatedly sailed around the earth, by advancing constantly in the same direction; arriving at length at the port from whence they departed.

Thirdly, On the ocean the horizon appears to be the circumference of a circle, and by the aid of geometry it can be *proved* to be really so. Indeed, any where on land or at sea the visible portion of the earth's surface is circular, and the higher we ascend above the level of the ocean, the larger does this circle become. At the top of Mount Ætna, 10,872 feet high, one-four thousandth ($\frac{1}{4000}$th) part of the surface of the earth is beheld, while from a balloon elevated 25,000 feet above the ocean, the sixteen hundredth part ($\frac{1}{1600}$th) has been seen. The fact that the visible portion of the earth's surface is *circular*, at what place soever an observation is made, can be accounted for only upon the supposition that the earth is *spherical;* and this point may be illustrated in the following manner. If we take an orange to represent the earth, and cut off a smooth slice from any side of it, the outer surface of the slice may be regarded as the visible portion of the earth's surface seen by a spectator. A single glance will show that the bounding line of this surface is the circumference of a circle. If instead of a globular body, like an orange, we take a lemon, the slices or sections will be circular, only when they are cut off perpendicular to a line joining the two ends. If a slice is cut off from the side, it will be oval in shape. Indeed, what body soever is taken, the sections made on any side of it, will not be circular except that body is a sphere.

Fourthly, When the sun, earth, and moon are so situated that they are all in the same straight line, the earth being between the others, it casts a shadow upon the moon. This *shadow* is seen to be *circular in form*, thus proving that the earth is round.

the surface of the earth from the sky and limits our view. Its full meaning is explained in Art. 36, 37, and 38.

Fifthly, Since the sun, and the nearest heavenly bodies are seen to be *round*, we naturally infer that the earth does not constitute an exception, but has also a similar form.

Sixthly, From observations and actual measurements, mathematicians are able to compute the distances of places on the earth's surface from its centre; in numerous places widely differing in latitude and longitude these distances *have been computed*, and are found to be in all instances *nearly equal*. This fact proves the spherical shape of the earth, since a sphere alone of all solid bodies possesses the property, that the distance from the centre to any point on its surface is everywhere the same.

In view of all these facts we conclude that the earth is a body *having a curved surface, that it is* nearly *spherical* in shape, and *rests upon nothing*.

23. We say *nearly spherical*, for according to the most accurate observations and refined calculations of astronomers, the earth swells out at the equator, the diameter which passes through it from pole to pole,[1] being about one three hundredth part ($\frac{1}{300}$th) shorter than any diameter that passes through the equator. To such a solid geometricians have given the name of *oblate spheroid*.

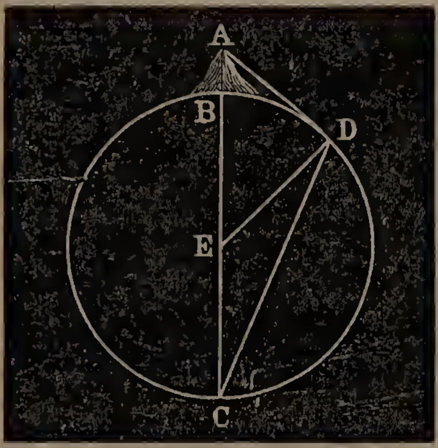
24. Size of the Earth. The diameter of the earth can be approximately determined in the following manner. Regarding it as a sphere, let BDC, in Fig. 13, represent a section of the earth through its centre, and AB, the height of a mountain above the sea level; while AD is an imaginary line drawn from the top of the mountain touching the earth at D, on the distant horizon.

Now a mathematician can easily obtain by the aid of

1. The *polar diameter* of the earth is the imaginary line or axis about which the earth rotates, like a wheel on an axle. Its extremities are the poles of the earth. A diameter drawn at right angles, to the polar diameter, and passing through the centre of the earth is an *equatorial diameter*. (See Fig. 12.)

Is the earth exactly spherical? How much shorter than the equatorial diameter is the polar? What is the geometrical name of a solid body shaped like the earth? Explain the first method by which the diameter of the earth can be nearly determined?

FIG. 13.



A SECTION OF THE EARTH.

trigonometry[1] both the height of the mountain AB, and the length of the line AD, and geometry then informs us that there are such relations existing between the lines AD, AC, and AB, as can be expressed by the following proportion; viz., AB: AD: : AD: AC. The length of the line AC, is then ascertained by the rule of three.

AC, therefore equals

$$\frac{A\,D \times A\,D}{A\,B.}$$

Subtracting now the height of the mountain AB, from the length of AC, and there remains the length of BC, the diameter of the earth. Thus if a peak of the Andes, 4 miles high, is just visible on the Pacific Ocean at the distance of $178\frac{1}{4}$ miles, the diameter of the earth and the height of the peak (AC) would together equal

$$\frac{178\frac{1}{4} \times 178\frac{1}{4}}{4}$$

or 7,943.26 miles; diminishing this quantity by four we have 7,939.26 miles for the diameter of the earth. Proceeding then by the common rule for finding the circumference of a circle from the diameter, we multiply 7,939.26 by the number 3.14159 which gives a product of 24,942 miles for the circumference of the earth[2].

1. Trigonometry "that science which teaches how to determine the several parts of a triangle from having certain parts given."

2. Another solution is here given for those versed in algebra and geometry, E being the centre of the circle, let x = the radius BE, or ED, then, $(x + 4)^2 = x^2 + \overline{178,25}^2 \therefore x^2 + 8\,x + 16 = x^2 + 3,1773.0625 \therefore$

25. There exists another method for determining the size of the earth, which was employed by Eratosthenes, a celebrated astronomer, who flourished at Alexandria in Egypt, about 200 years before Christ. The mode of operation may be explained as follows: If it were possible for a person to start, for instance, from Washington, in a north or south direction, measuring round the earth until he came to Washington again, he would have passed over *three hundred and sixty degrees* of latitude. Now on the supposition that the earth is a sphere, it is clear that any number of degrees of latitude, as five for example, bears the same relation to the length of the same number of degrees in *miles*, as three hundred and sixty degrees of latitude to the entire circumference of the earth, measured in miles; since five is the same part of three hundred and sixty, as the length of five degrees in miles, is of the circumference of the earth in miles.

26. It was in this manner that Eratosthenes proceeded. He found that Alexandria in Egypt, was 500 miles north of Syene, a town on the frontiers of Nubia, and that the difference in latitude between the two places was $7\frac{1}{5}$ degrees. From these measurements he was enabled to make the following proportion, $7\frac{1}{5}$ degrees : 500 miles : : 360 degrees : the circumference of the earth in miles. The fourth term therefore equals

$$\frac{360 \times 500}{7\frac{1}{5}}$$

or 25,000 which expresses the circumference of the earth in miles. 25,000 *divided* by 3.14159 gives the diameter. In *round numbers*, we may therefore consider the *diameter* of the earth to be 8,000 miles in extent and the *circumference* 25,000. But astronomers have not remained contented with these rough approximations towards the truth, since all accurate knowledge of the distances, magnitudes, and motions of the other heavenly bodies, depends upon our knowing the exact dimensions of the earth. The latest and most elaborate

$8x = 31757.0625 \therefore x = 3969.63$, which multiplied by $2 = 7939.26$ the diameter of the earth.

Explain the method employed by Eratosthenes. What is the length of the diameter of the earth in miles, in round numbers? What that of the circumference?

researches demonstrate that the length of the *polar diameter* of the earth, is 7,899.170 miles, and that of the *equatorial diameter* 7,925.648. The distance from the general surface of the earth to the centre, being at the equator 13.239 miles greater than at the poles.

27. ROTATION OF THE EARTH. To every one endowed with vision, it is one of the most familiar sights in nature to behold the sun ascend the eastern sky, attain its noontide splendor, and at length set beneath the western horizon. And when night approaches the starry host appear moving in the same order; their bright ranks rising successively above the eastern horizon, and passing over in ceaseless march to the west. This motion of the celestial bodies can be explained in *two ways*, either by supposing that the earth is *at rest*, and all the luminaries of the sky actually revolve about it, or that their motion is only *apparent*[1], the earth itself really rotating while the celestial orbs remain immoveable.

The first theory was received as the truth for ages, until the discoveries of scientific men at length showed its falsity, and established by undeniable proofs, the fact of the *rotation of the earth on its axis.* Some of these proofs we shall now state.

28. *First proof.* The form under which atoms of matter unite in obedience to their mutual attraction, and uninfluenced by any other force, is that of a sphere. We behold this exemplified in the case of quicksilver spilled upon a floor, the small portions of which are seen assuming a globular shape, the form being more perfect as the portion is smaller. Moreover if alcohol and water are mingled together, in such proportions as to have the same[2] specific gravity as olive oil, upon dropping a little

1. When a person sails from the shore with a steady wind, the shore apparently moves backward, while the ship seems to be stationary though the observer knows all the while that the true state of the case is exactly the reverse.

2. Two substances are of the same specific gravity, when being equal in size they are also equal in weight.

What are the lengths of the equatorial and polar diameter according to the best and latest computations? How much farther is the surface of the earth from the centre at the equator than at the poles? In how many ways can the motions of the celestial bodies be explained? What are those ways? Which one for ages was received as true? Has it been proved false.

of the latter into the mixed fluid, the drops of oil uninfluenced by the gravitation of the earth, take the shape of *spheres* as long as they are *at rest.* But if now a slender wire is passed through the centre of one of these *oil-globes*, and it is made to revolve by turning the wire rapidly round, it flattens about those points where the wire passes through, which represent the poles of the oil-globe, while it swells out at the middle or equatorial parts, assuming the form of a spheroid, in consequence of the centrifugal[1] force increasing from the poles to the equator.

29. In like manner if the earth at the beginning consisted of yielding materials, as many able geologists suppose, it must have assumed the shape of a sphere by virtue of the mutual attraction of its particles, and retained that shape forever, provided it did *not rotate* on an axis; but if it did *thus rotate*, it must have taken the form of a spheroid, the amount of the excess of the equatorial diameter over that of the polar, depending upon the rapidity of the rotation.

30. Taking as the ground-work of his computation the known dimensions of the earth, and assuming as a fact its revolution in twenty-four hours; Sir Isaac Newton calculated what form the earth must of necessity take. He found it would be a spheroid, and that the equatorial diameter, would exceed the polar diameter by a certain length, which is almost exactly equal to the difference which has since, by the actual measurement of the earth, been shown to exist between them, viz., twenty-six miles and nine-tenths of a mile.

The result of the computation being thus proved true, the assumed point upon which this result is founded,

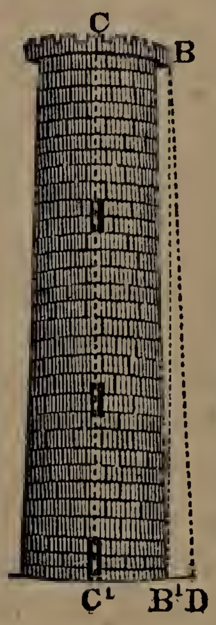
1. *Centrifugal force*, is that which tends to make a revolving body depart from the centre of motion. Water flying from the circumference of a revolving grindstone, is an example. When bodies revolve in different circles, in the *same time* the centrifugal forces are directly proportioned either to the radii or circumference of the circles. The centrifugal force, reckoning from the poles of the earth to the equator, will therefore increase in the ratio of the length of the parallels of latitude.

State the first proof that the earth rotates on its axis? What was the result of Sir Isaac Newton's computation?

must be also true. The rotation of the earth is, therefore, no longer a supposition, but a fact.

31. *Second Proof.*—DEVIATION OF FALLING BODIES FROM A VERTICAL LINE. If the earth has indeed a rotation on its axis, all the particles that compose it, and all the bodies upon its surface, have a greater centrifugal force in proportion as they are more distant from the axis of rotation. Thus, a particle of dust upon the top of a carriage wheel in rapid motion, flies off in advance with greater velocity than if it had been situated nearer the axle; and in like manner, if the earth is actually rotating from west to east, a ball upon the *top* of a lofty tower, will move with greater speed towards the east than when placed at the *bottom*, because in the first position it is farther removed from the axis of rotation, than in the second.

FIG. 14.



32. With this principle in view, a simple experiment reveals the fact of the rotation of the earth. If the earth were at rest, a bullet dropped from the top of a high tower, would descend in a line parallel to the perpendicular height of the tower; the point where it struck the ground, and the point whence it started, being at the same distance from the middle of the tower. But upon making the experiment it is found that when the bullet is dropped on the east side of the tower, it reaches the earth at a *point farther east* from the centre of the tower, than the place of starting. Now this circumstance can only be explained, on the supposition that the earth rotates from west to east, and imparting the greatest centrifugal force to the bullet, when at the top of the tower, and the least at the bottom, it necessarily gives it an easterly motion beyond the perpendicular. Thus, in Fig. 14, CC^1 represents the perpendicular height of a tower, BB^1 the same, and BD the path of a bullet dropped from the top of the tower on the eastern side.

 Give the second proof.

The distance from the place of starting to the centre of the tower; viz., CB, is less than the distance of the place where the bullet strikes the earth from the centre of the tower, viz., C^1D. (1)

33. *Third Proof.*—VARIATION IN THE WEIGHT OF BODIES. It has been discovered by philosophers, from experiments with the pendulum, that a body weighing 194 pounds at the equator of the earth, would weigh 195 pounds at the poles, or in other words, would gain $\frac{1}{194}$th part of its weight by such a removal. It might at first be supposed, that this circumstance is owing to the fact, that a body at the poles is thirteen miles nearer the centre of the earth than at the equator, and thus being more powerfully attracted would of course weigh more.

34. This view is correct as far as it goes; it partially explains the difference in weight, but does not account for the entire change. A body, by being simply thirteen miles nearer the centre of the earth in one place than in another, would have its weight increased one five hundredth and ninetieth part ($\frac{1}{590}$); but as we have stated, multiplied experiments with the pendulum show, that a body so situated at the poles would have its weight increased $\frac{1}{194}$th part. The difference between this quantity and $\frac{1}{590}$th, viz., $\frac{1}{289}$th, remains unaccounted for, on the supposition that the earth is an oblate spheroid *at rest*, whose surface at the poles is thirteen miles nearer the centre than at the equator. But when we regard the earth as rotating on its axis once in twenty-four hours, the difficulty vanishes, for at the equator bodies are acted upon by two forces; 1st, the *force of gravity* which draws them towards the centre of the earth, and is a measure of their weight; and 2d, the *centrifugal* force of the earth, which tends to make them fly away from the centre, and diminishes their weight. At the poles this centrifugal force is nothing. Now at the equator, the centrifugal force is directly opposed to the force of

1. An experiment of this kind was performed by Benzenberg, a German, in 1804, in Michael's Tower, at Hamburg, 30 balls being dropped from the height of 235 feet. The deviation from the perpendicular was *one-third of an inch.*

Give the third proof.

gravity, and diminishes its effect; thus lessening the weight of bodies, according to the profound investigations of eminent mathematicians $\frac{1}{289}$th part. The fact of the variation in the weight of bodies in different parts of the world can thus be fully accounted for, but if the rotation of the earth is denied, it remains inexplicable.

35. In view of these and other equally important facts which will appear in the course of our investigations, we infer *that the earth rotates as though revolving on a diameter, at right angles, to the plane of the equator.* The period of rotation as we shall hereafter see, is divided into twenty-four equal parts, called *hours.*

CHAPTER II.

THE HORIZON.

36. Horizon is an astronomical term derived from the Greek word *orizon* signifying *boundary*, and of these boundaries there are *two.*

Sensible Horizon. The first is the *sensible* or *visible horizon*, of which we have already spoken. It is the line apparently separating the earth and sky, and which a spectator upon the expanse of ocean, or on a vast unbroken plain, perceives to be a *circle.*

The plane of the visible horizon is regarded as touching the earth at the point where the spectator stands, though strictly speaking this is not the case, since on account of the depression of the visible horizon the point where the spectator stands is a little above its plane. This is evident by referring to Fig. 15, where the circle E represents a section of the globe, S the place of the spectator, and the circular line VH a part of his visible horizon. Now it is evident at a glance, that owing to the curvature of the earth the plane of the visible horizon, which takes the direction V^1VHH^1, is neces-

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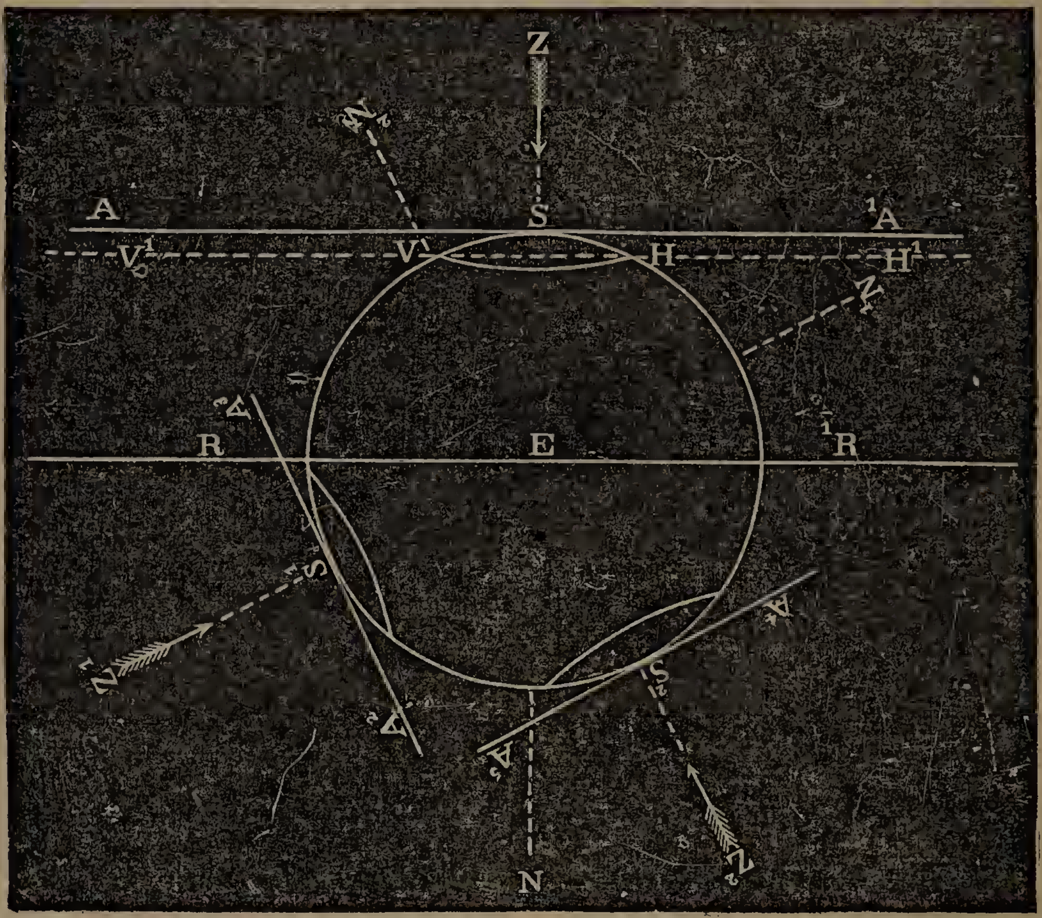
What inference is made in view of the facts adduced? How is the period of rotation divided? What does Chapter Second treat of? What is the meaning of the term *horizon*? Give the meaning of the term *sensible horizon*, and explain from figure

sarily below the parallel plane that touches the earth at S, the place of the spectator, and takes the direction of ASA¹. Nevertheless the difference in distance between

FIG. 15.



HORIZON EXPLAINED.

the two planes is usually so small that they are generally regarded as coinciding; the plane of the horizon being supposed to pass through S.

37. RATIONAL HORIZON. The second or *rational horizon* is a vast imaginary circle whose plane passes through the centre of the earth, dividing the earth and sky into two hemispheres, and is parallel to the plane of the visible horizon. It is also represented in direction in Fig. 15, by the line RR¹.

At the earth these planes are nearly 4,000 miles asunder, or half the diameter of the globe, but when we extend them in imagination as far as the fixed stars,

Of *rational horizon*, and explain from figure How far apart are these planes at the earth? Why will these planes appear to meet at the distance of the fixed stars?

they are there supposed to meet.[1] For a spectator at such a distance from the earth, if he could possibly discern our globe, would see it as a mere point; and the planes of the two horizons would *apparently* meet, there being no visible distance between them. In the same manner, if a person on the earth could really behold the planes of the horizons as visible surfaces, actually extended in all directions to the fixed stars, he would see them coinciding, and intersecting the concave[2] sphere of the visible heavens in the same line; for the space of 4,000 miles by which they are separated, would at this immense distance apparently dwindle also in this case to a mere point. For these reasons it is said that the planes of the sensible and visible horizons cut the concave surface of the distant heavens in the same line.

38. PLANE OF THE HORIZON NOT FIXED IN SPACE. We have said that the plane of the horizon touches the surface of the earth at the point where the spectator stands, or in other words, is at right angles at this point to a plumb-line[3] passing through this same point. Now the direction of the plumb-line varies at every point of the earth's surface. Consequently, there are as many horizons both sensible and rational as there are such points; and the planes of these horizons take all possible directions. Thus, in Fig. 15, if S, S^1, S^2, represent the stations of different spectators upon the earth's surface, it is clear that the planes of the horizons of each, viz, AA^1, A^2A^3, A^4A^5, take different directions.

1. Strictly speaking two parallel planes or lines extended to any distance can never *actually* meet, they only *appear* to the eye to meet. Thus, to the view of a person standing on a rail-road where the track is straight for a considerable length, the parallel rails in the distance seem to approach nearer and nearer to each other, according as they are more remote from the spectator, though they are really as far apart in one place as in another. If the straight track is very long they will appear to meet and come to a point.

2. If a sphere is hollow the inner surface is termed a concave sphere. The visible heavens appear to have this form.

3. If a ball of lead is tied to one end of a string, and the other end held up so that the ball can swing freely, the direction the string takes when the ball is at rest is the direction of the plumb-line. *Plumbum* is the Latin word for lead.

Is the plane of the horizon fixed in space? How many horizons are there? Explain from figure.

39. ZENITH AND NADIR. The point in the heavens, in the direction of the plumb-line, exactly over the head of an observer, is the *zenith;* and the point in the heavens beneath him in the opposite direction is the *nadir.* The zenith and nadir are the poles of the rational and sensible horizons, since they are points in the concave sphere of the heavens, ninety degrees distant in every direction from the common line where the planes of both these horizons cut this sphere.

Since the horizon of an observer changes at every step, it necessarily follows that his zenith and nadir also change. The zenith of the place directly beneath us on the opposite side of the earth is our nadir, and its nadir our zenith. In Fig. 15, Z is the zenith at S, and N the nadir. At S^1, Z^1 is the zenith and N^1 the nadir. At S^2, Z^2 is the zenith and N^2 the nadir.

40. CHANGING ASPECT OF THE HEAVENS ARISING FROM THE ROTATION OF THE EARTH. Having learned the fact of the rotation of the earth, and of the full meaning of the term horizon, we will now contemplate the aspect of the starry sky, remembering all the while that we are not stationary, but standing on the surface of a rolling ball.

41. If, in our latitude, upon a clear evening, we take a position upon some commanding eminence, we perceive the whole of the overarching sky studded with multitudes of glittering stars, down to the very line which separates the earth from the heavens. Some bright cluster may perhaps be seen just hanging above the western horizon, while another may arrest our attention in the eastern sky.

Time glides away unheeded as the glories of the splendid scene pass in review before us, and when we turn our eyes again towards the western group it is no longer visible, but has sunk beneath the horizon, while the cluster in the east has attained a loftier elevation.

42. By a longer and closer observation we find that all the stars have this common motion from east to west, and that they appear to move in *circular paths.*

What is meant by zenith and nadir? Having now learned the meaning of the term horizon, to what is our attention next directed? In what direction do all the stars [illegible]

It is moreover noticed, that the stars in passing over from the eastern to the western horizon, describe greater or less portions of the circumference of a circle, according to their different positions in the heavens. Thus, the farther to the north a star rises, the greater is the arc[1] it passes through, and the longer it is visible, till at last we observe stars far in the north which never sink below the horizon, but revolve about some unseen centre situated high up in the northern sky. On the contrary, in the southern quarter of the heavens the arcs of circles described by the stars are seen to be smaller and smaller as our eyes are directed to points more and more remote towards the south; until, at the southern extremity of the heavens, the bright luminaries scarcely lift their heads above the horizon before they begin again to descend and withdraw from our view.

43. Our knowledge of the rotation of the earth renders these appearances perfectly intelligible. The stars are not *really* in motion, but only *appear* to be, for the earth in its rotation from west to east is constantly depressing the eastern part of the horizon and elevating the western, so that a star *rises* in consequence of the eastern horizon being carried *below* it, and *sets* because the western horizon is carried up to it and *above* it.

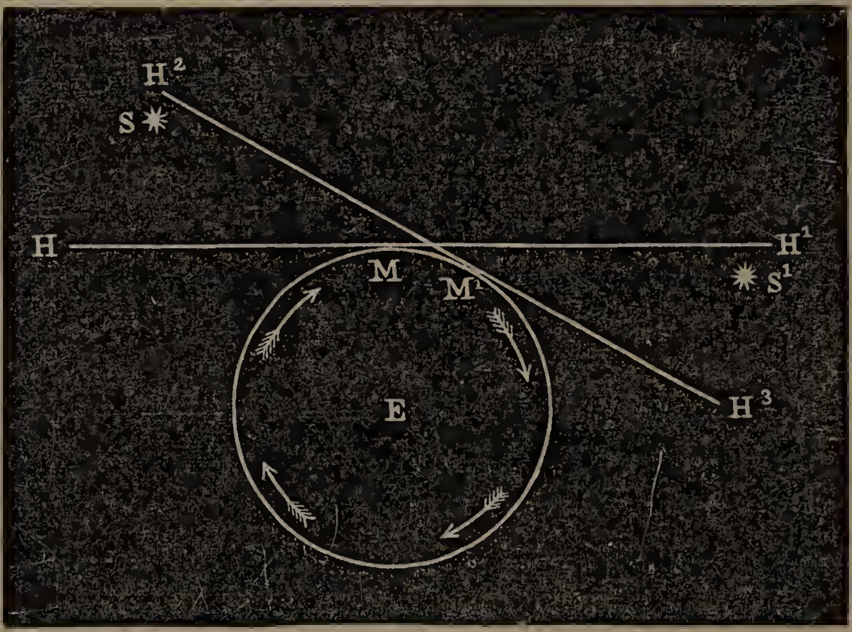
44. This point is illustrated in Fig. 16, where circle E represents the earth rotating from west to east,[2] as shown by the direction of the arrows. If a person is at M, on the surface of the earth, the plane of his horizon is in the line HH^1, and the star S is above his western horizon, and the star S^1 below his eastern horizon. But when the earth in its rotation brings the person into the position M^1, the plane of his horizon has been so changed as to take the direction H^2H^3, and the star S has set

1. *Arc*, any portion of the circumference of a circle.
2. The phrase, *revolving from west to east*, is explained in Art. 134.

pear to move, and in what kind of path? Do they all describe, in our own latitude, equal portions of the circumference of a circle, while above the horizon, and are they all visible for the same length of time? What is said respecting the stars situated in the northern portion of the heavens, and what of those in the southern? How is the motion of the stars explained? Are they really in motion? How do you explain the *rising* and *setting* of a star? Illustrate from the figure

FIG. 16.

WEST.



EAST

CHANGING HORIZONS.

below the western horizon, while the star S¹ has risen above the eastern.

45. Why the Stars appear to describe Circles. The *apparent circular paths* of the stars are the result of our own circular motion on the surface of the earth; for, not perceiving ourselves to move, these orbs appear to have the kind of motion that really belongs to us. This illusion is the same as that which happens when two trains of cars coming from opposite directions stop side by side in a depot, and a passenger in one looks out at the opposite stationary train, the moment his own starts; unconscious of his own motion, the train at his side appears to him to move in a contrary direction to that in which he himself is actually proceeding. If his own train moves in a straight line, the other appears to do so likewise; but if the former moves in a circular track, such is the apparent course of the latter. In like manner a spectator moving in a circle upon the rolling surface of the globe, sees the stars moving in circles in a direction contrary to his own, imagining himself all the while to be at rest.

46. Why these Circles Differ in Size. The rea-

Explain why the stars appear to describe *circles*, and why these circles apparently diffe in size.

son why the stars apparently describe circles of different magnitudes is the following. If lines were drawn from the centre of the globe to the heavens, in various directions from the *equator* to the *poles*, they would describe, as the earth revolved, *circles in the sky;* whose *angular magnitudes* would depend upon the several inclinations of these lines to the axis of rotation. Thus a line at *right angles* to this axis would pass through the *equator*, and describe the *greatest circle;* while another, down through a parallel of latitude *fifty degrees* from one of the poles, would describe a circle in the heavens of *fifty degrees radius*, and pass through the *stars in the zeniths* of the regions situated on this parallel. A line drawn from the centre to either pole would evidently *coincide* with the axis of rotation; it could therefore describe no circle, and would be *at rest.* Now, since the motion of the earth produces a contrary apparent motion in the stars, the orbs directly above the earth's equator will describe gerater circles than the stars that pass through the zeniths of regions lying north and south of the equator. And the circular paths of the stars will become smallerandsmaller as they are described nearer the two opposite points in the heavens, to which axis of the rotation of the earth is directed. These points are termed the *north* and *south poles* of the heavens, and around them all the luminaries of the celestial canopy appear to revolve. They are situated directly above the poles of the earth, and any star at these points would be stationary. One degree and a half distant from the north pole of the heavens a bright star is found, which is termed the *pole star.*

47. CHANGING ASPECT OF THE HEAVENS ARISING FROM CHANGE IN LATITUDE. A person standing on the surface of the earth at the *equator*, has the plane of his horizon parallel to the axis of the earth. The poles of the heavens are consequently situated in this plane, and his horizon appears to pass through them. All the circles

What is meant by the north and south poles of the heavens? Would a star at these points appear to move? How far from the north pole of the heavens is the pole star situated? Describe the celestial appearances of the equator.

of daily motion[1] are therefore perpendicular to the horizon. A star which rises in the east passes directly overhead and sets in the west, and each orb describing half a circle above and half below the horizon is, therefore, visible for twelve hours, and then invisible for an equal space of time. Far in the north is seen the pole-star, which rises above the horizon one degree and a half, slowly revolving in a circle only three degrees in diameter in the space of twenty-four hours.

48. If the observer now advances northerly his horizon constantly changes in position, being depressed below the north pole of the heavens, and elevated above the south the same number of degrees and parts of a degree that corresponds to his latitude. Thus, if he has arrived at *ten degrees, north latitude*, the northern pole is ten degrees above his horizon, and the southern ten degrees below it. If, at *fifty degrees, thirty minutes, north latitude*, the north pole is fifty degrees and thirty minutes above the horizon, and the southern as much below it. And if it were possible for a person to attain the distance of ninety degrees, north latitude, and stand upon the northern pole of the earth, his horizon would be parallel to the equator, the north pole of the heavens would be ninety degrees from the horizon, that is, in the *zenith*, and the southern pole of the heavens would coincide with his *nadir*.

49. This change in the relative positions of the poles of the heavens and the horizon produces a corresponding change both in the inclination of the circles of daily motion to the horizon, and in the period of visibility of different stars. For, all the stars apparently revolve in circles, at right angles to the imaginary line joining the poles of the heavens, called the *axis of the heavens*, and as the north pole of the heavens is elevated more and more above the horizon, these circles of daily

1. By the term *circles of daily motion*, is understood the circles described by the heavenly bodies in their apparent daily motion from east to west.

What changes occur as an observer advances towards the north? If he stood upon the pole where would the north pole of the heavens be? Where the south? What corresponding changes are produced by the variations in position incident to the poles of the heavens and the horizon? What is the axis of the heavens?

motion must cut the horizon more and more obliquely, until at the north pole of the earth a person would see the stars revolving about him in circles parallel to the horizon.

50. Moreover, when the north pole of the heavens rises above the horizon, and the south sinks below it, it is only those stars that are situated directly above the earth's equator which are visible in a clear sky for twelve hours above the horizon, and are absent as long below it; since the centre of their circle of daily motion is alone in the plane of the horizon. All the stars to the north of the equator have the centres of their circles of daily motion more and more elevated above the plane of the horizon according as they are situated farther to the north. The circumferences of the circles they describe, it is true, become smaller and smaller, but the arcs described above the horizon are proportionally larger; and consequently the time that a star is visible increases up to a certain limit from the equator towards the north.

51. Circle of Perpetual Apparition. There are stars which never set; for when an orb is at a less distance from the pole than the horizon is, it is evident that such a star will continue to revolve about the poles without ever sinking below the horizon. A circle around the elevated pole having a radius equal to the altitude of the pole above the horizon is called the *circle of perpetual apparition*, because the stars within it never set. This circle changes in size with the change of latitude. In latitude ten degrees its radius is ten degrees; in latitude fifty degrees, fifty degrees; and at the pole it would be ninety degrees, comprehending the entire visible heavens, every star above the horizon revolving in a circle parallel to it.

52. Let us now direct our attention to the stars towards the south pole, our place of observation being the northern hemisphere. In this direction the axis of the heavens is depressed below the horizon, the south pole of the

How would the stars appear to revolve to a spectator at the north pole? What is said respecting the times of visibility of stars at the equator and north of the equator? Are there stars which never set? What is meant by the circle of perpetual apparition? State what is respecting the extent of the arc described by stars south of the equator, and of the extent of their times of visibility.

heavens being as far below the horizon as the north pole is above it. The centres of the circles of daily motion described by the stars being in this region below the horizon, the arcs they pass through above the horizon are less than semi-circumferences,[1] growing smaller and smaller the farther to the south a star is situated. Their periods of visibility will decrease in like manner, until we arrive at a point in the southern heavens where a star just glimmers for a moment upon the horizon and then sets again.

53. Circle of Perpetual Occultation. The stars that are situated at a less distance from the south pole of the heavens than the pole is depressed below the horizon, will never in their daily revolution come into sight. A circle around the depressed pole, having a radius equal to the distance of this pole below the horizon, is called the *circle of perpetual occultation*, because the stars within it never rise to our view.

54. Like the circle of perpetual apparition, that of occultation varies with the variation of latitude, and at the same place the magnitude is the same, since one pole is elevated the exact amount that the other is depressed. Thus, in north latitude ten degrees, the south pole of the heavens is ten degrees below the horizon, and the radius of the circle of perpetual occultation is also ten degrees. In north latitude fifty degrees, it is fifty degrees, and at north latitude ninety degrees, that is, at the north pole of the earth, it comprises the entire half of the heavens below the horizon.

55. We have thus far described the changing aspect of the heavens, by supposing a traveler to proceed from the equator towards the north; were he to take the opposite direction and move towards the south, the phenomena we have described would be exactly the same, only reversed in position. Thus, the plane of the horizon would dip towards the south, the north pole of the

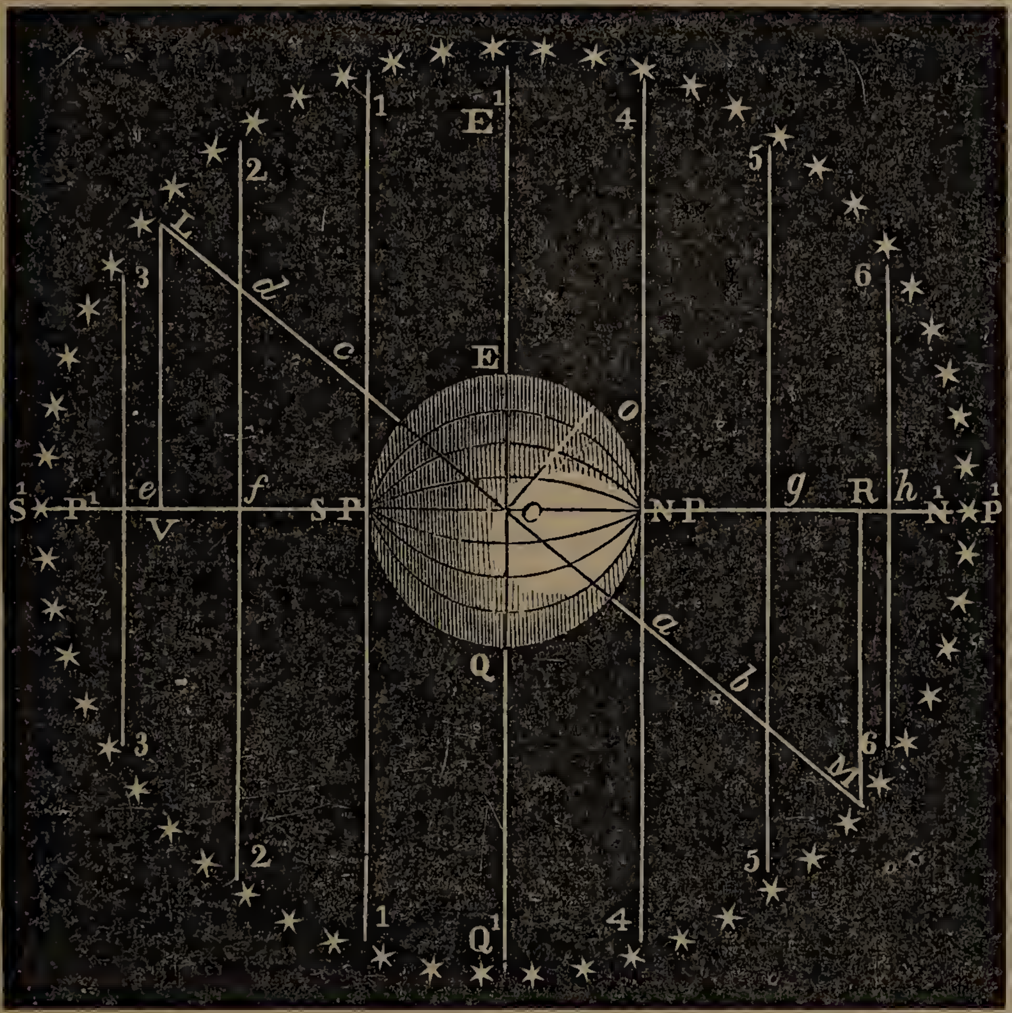
1. A semi-circumference is half a circumference.

What is meant by the term circle of perpetual occultation? How does the circle of perpetual occultation compare in extent with that of perpetual apparition? What would be their extent to an observer at either pole of the earth? State what is said respecting the phenomena of the heavens when the observer advances to the south.

heavens would be depressed, the southern elevated, and the stars would be longer above the horizon south of the equator than north of it. To an observer at the south pole of the earth, the south pole of the heavens would be in the zenith, and the circles of daily motion would be parallel to the horizon. The circle of perpetual apparition would be around the south pole of the heavens, and that of occultation about the north, and so on.

56. These remarks may be still farther impressed upon the mind by studying the annexed figure, where

FIG 17



VARYING ASPECT OF THE HEAVENS, ARISING FROM CHANGES IN LATITUDE.

the outer starred circle represents a section of the concave sphere of the heavens, C the earth, SP and NP its north and south poles, the line SPNP its axis of

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Explain the figure.

rotation, and EQ its equatorial diameter. S^1P^1 and N^1P^1 are the north and south poles of the heavens, and the imaginary line, $S^1P^1N^1P^1$, the axis of the heavens, about which the stars apparently revolve. E^1Q^1 is the diameter of the celestial equator.[1] 1, 1; 2, 2; 3, 3; &c., are the diameters of other circles, in the circumferences of which the stars appear daily to revolve. If a spectator is at the equator, at E, his sensible horizon coincides with his rational, $S^1P^1N^1P^1$, at the vast distance of the fixed stars; and the poles of the heavens, are consequently upon his sensible horizon. Thus situated, we see that the circles of daily motion are perpendicular to his horizon, and each of the stars that are seen at all, apparently describes a semi-circumference above and a semi-circumference below the horizon, being for twelve hours visible and for twelve hours invisible. This is evident, since the diameters of these circles have their centres, as V, *f*, *g*, *h*, &c., in the plane of the horizon. If the observer moves to O, *north latitude*, *forty degrees*, LM becomes his rational horizon. The north pole of the heavens is elevated, and the south depressed forty degrees.[2] The radius of the circle of perpetual apparition, is MR, whose angular breadth is also equal to forty degrees, and LV, having the same extent, is the radius of the circle of perpetual occultation. The circles of daily motion are here oblique to the horizon, LM, and the stars north of the equator are consequently above the horizon a proportionally *longer* time than twelve hours, as they are nearer the circle of perpetual apparition. South of the equator they are above the horizon for a proportionally *shorter* space than twelve hours, the nearer they approach the circle of perpetual occultation. These points are evident when we compare the parts of the lines, 1, 1; 2, 2; 4, 4; and 5, 5; which are above the horizon, LM, with the parts that are below,

1. The diameter of the celestial equator is the diameter of the earth's equator extended to meet the starry heavens. See Art. 64.

2. N^1CM is an angle of forty degrees, and as the rational horizon of the spectator at O coincides with his sensible horizon at the distance of the fixed stars, the angle of elevation of the pole, N^1P^1, at his station, O, on the surface, will also be forty degrees.

viz., 5*b*, *b*5; 2*d*, *d*2, &c. At the north pole, NP, the horizon takes the direction of the line E^1Q^1, the north pole of the heavens, N^1P^1, is in his zenith, and all the stars in the hemisphere, $E^1N^1P^1Q^1$, revolve in circles parallel to the horizon: E^1C is at once the radius of the circle of perpetual apparition and occultation, since all the stars above the horizon never set, and those below it never rise above it. If the observer moves toward the south pole of the earth, it is clearly seen that these appearances are exactly reversed.

57. LATITUDE OF ANY PLACE EQUAL TO THE ELEVATION OF THE POLE OF THE HEAVENS. From what has been just stated, it is evident that the latitude of any place is equal to the altitude of the pole of the heavens above the horizon. For we have seen that at the equator, where the latitude is nothing, the elevation of the pole is nothing; at latitude forty degrees the elevation of the pole is forty degrees, and at the poles of the earth, or latitude ninety degrees, the pole of the heavens is ninety degrees from the horizon, and is in the zenith. And the same is true for every latitude, either north or south of the equator.

CHAPTER III.

ON THE MODE OF DETERMINING THE PLACE OF A HEAVENLY BODY.

58. THE first object of the geographer in describing the earth with its kingdoms, cities, mountains, oceans, seas, islands, &c., is to determine their exact position on the surface of the globe. This he obtains in the case of a city, for instance, by finding *first*, how many degrees, minutes, and seconds, it is situated *east or west* from a great circle, called a *meridian*,[1] passing through the poles of the earth and some assumed point on its surface, as a

1. See Art. 63 for the meaning of the term *meridian*.

What is the latitude of any place equal to? What is the subject of Chapter III? What is the first object of the geographer? In what manner does he determine the position of a city? Give an instance.

celebrated observatory; and *secondly*, its distance in degrees, minutes, and seconds, *north or south* of the great circle called the *equator*, passing through the centre of the earth at right angles to its axis of rotation. Thus, for instance, the position of New York City Hall is fixed by finding first, that it is situated seventy-four degrees, and three seconds (74° 00′ 03″) west of the meridian passing through Greenwich Observatory. This is its *longitude*. Next, that it is distant north of the equator forty degrees, forty-two minutes, and forty-three seconds (40° 42′ 43″). This is its *latitude*. These two measurements are sufficient to mark with precision its situation upon the globe, for no other spot on its surface can have this latitude and longitude.

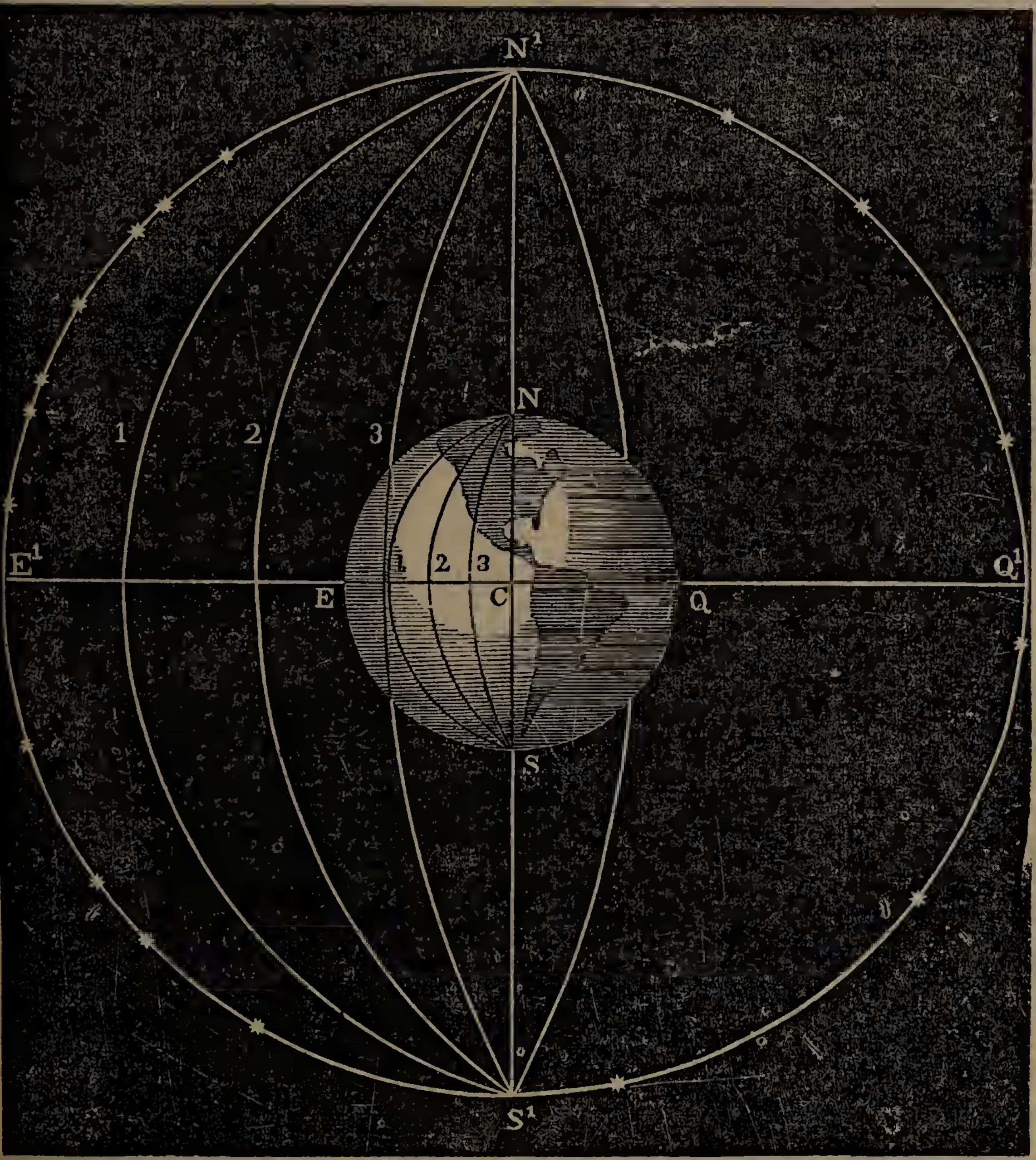
59. In a similar way the astronomer determines the position of stars in the concave sphere of the heavens, by measuring their angular distances from the planes of *two great circles, at right angles* to each other. But in order to understand intelligibly the method pursued, we must first give our attention to the manner in which both the globe and the sky have been intersected by imaginary lines and circles, and to the relations existing between them; bearing constantly in mind that these lines and circles are all pure fictions, not one of them really existing in nature, but that they have been invented by astronomers and geographers simply for the purpose of arriving at certain results. Some of these we have already described, but shall refer to a few of them again, in this connection, since it is highly important that the scholar should always have in his mind a clear idea respecting these imaginary circles and lines.

60. Celestial Sphere, Poles, Axes, and Meridians. The *celestial sphere* is the *concave sphere of the heavens*, in which the stars appear to be set. The *poles* of the earth are the extremities of that imaginary line upon which it revolves; the latter is called the *axis*. If any plane passes through the poles and the axis in any di-

How does the astronomer determine the position of a star? What is said respecting the circles and lines employed by astronomers for this purpose? What is meant by the celestial sphere? The poles of the earth? Its axis? Terrestrial meridians. Explain from figure.

rection, its intersection with the surface of the earth is a circle, and is called a *terrestrial meridian*. Thus, in Fig. 18, which represents the earth and the celestial sphere,

FIG. 18



THE EARTH AND THE CELESTIAL SPHERE.

the line NS is the axis of the earth. N, the north pole, S, the south pole, and NES, N1S, N2S, N3S, are terrestrial meridians.

61. The axis of the earth, extended in imagination

What is meant by the axis of the celestial sphere? The poles of the heavens?

each way until it meets the starry sky, becomes the axis of the *heavens*, or *celestial sphere*, around which all the stars appear to revolve. The extremities of this axis are the *poles of the heavens*. Thus, in the figure, where the outer starred circle represents a section of the celestial sphere, the line N^1S^1 is the axis of the celestial sphere, and N^1 and S^1 its north and south poles. The axis of the earth is that part of the axis of the heavens, which is intercepted between two opposite points on the earth's surface, and these two intercepting points are the poles of the earth.

62. If any plane passes through the poles and axis of the heavens in any direction, its intersection with the imaginary surface of the celestial sphere is a *celestial meridian*. A terrestrial and celestial meridian are, therefore, formed by one and the same plane; the first occurring when the plane is intersected by the surface of the earth, the second when it is cut by the concave sphere of the heavens. Thus, $N^1E^1S^1$, N^11S^1, N^12S^1, and N^13S^1, are celestial meridians; and NES, N1S, N2S, and N3S, their corresponding terrestrial meridians.

63. The plane of the meridian at any place is perpendicular to its horizon, and consequently passes through its zenith and nadir, dividing the visible heavens into two equal parts towards the east and west. For this reason this circle is called the *meridian circle*, because when the sun, in his apparent diurnal revolution, comes to the meridian of any place, it is there noon, or midday; the Latin word for mid-day being *meridies*.

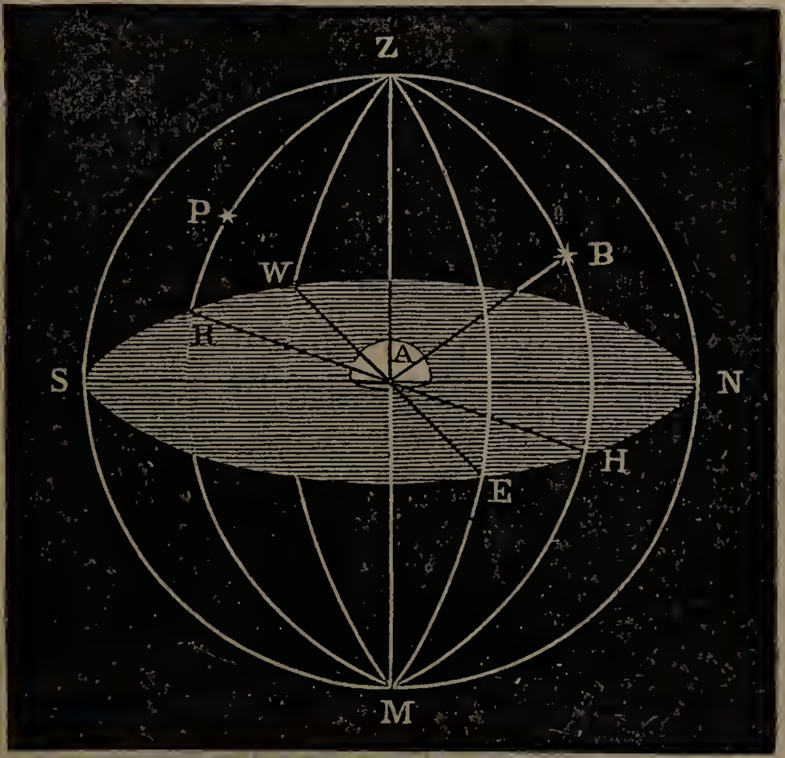
64. EQUATORS. If we suppose a plane passing through the centre of the earth, perpendicular to the axis of rotation, its intersection with the surface of the earth forms a circle called the *equator*, or *terrestrial equator*, and if this plane is extended in imagination to the fixed stars, its intersection with the celestial sphere is also a circle, called the *celestial equator*, or *equinoctial*. Thus, in Fig. 18, EQ is the equator, and E^1Q^1 the celestial

What is meant by celestial meridians? Explain from figure. What are the relative positions of the plane of the meridian of any place and the plane of its horizon? What is the meaning of the term meridian? What is the terrestrial equator? What the celestial?

equator. They appear as straight lines in the figure, because we see them in the direction of their planes.

65. VERTICAL CIRCLES. Vertical circles are those which are imagined to be formed by planes passing through the zenith, perpendicular to the horizon, and intersecting the celestial sphere. The vertical circle passing through the east and west points of the horizon is termed the *prime vertical*, while that which intersects the north and south points becomes a meridian. Thus, in Fig. 19, where A represents the earth, SZWMN the celestial sphere, Z the zenith, and the plane SWNE the horizon—PZHM is a *vertical circle*, WZEM the *prime vertical*, and SZNM a *meridian*.

FIG. 19



AZIMUTH AND ALTITUDE OF A STAR.

66. THE POSITION OF A STAR—HOW DETERMINED. The place of a star in the sky may be determined in *three* ways. *First*, by referring it to the planes of a *celestial meridian* and of the *horizon*. *Secondly*, by noting its distance from the planes of a given *meridian*

What are vertical circles? What the prime vertical? Is a meridian a vertical circle? Explain from figure. In how many ways is the position of a star fixed? Describe them

and the *celestial equator.* *Thirdly*, by referring it to the planes of a given *great circle*, and the *ecliptic.*[1]

67. AZIMUTH, AMPLITUDE, ALTITUDE, AND ZENITH-DISTANCE. Proceeding according to the first method, we should ascertain the situation of a star in the following way. Suppose the star is the beautiful luminary, Alpha Lyræ, and that we observe it in the east. Having previously found the plane of the meridian, by methods hereafter to be explained, we should now imagine a vertical circle to pass through our zenith and the star, cutting the horizon at right angles. Then, with the proper instrument, we should measure *on the horizon* the angle which the vertical plane makes with the meridian. This angle is called the *azimuth* of the star, and is reckoned from north to south when a star is north of the prime vertical, and from south to north when south of the prime vertical. The difference between the azimuth and ninety degrees is the distance of a star from the prime vertical, and is called the *amplitude.*

68. The next step is to ascertain the angular elevation of the star above the horizon, *measured on the vertical circle* passing through the orb. This angular distance is called the *altitude* of the star, and the difference between its altitude and ninety degrees is its *zenith distance.* By having the azimuth and altitude of a star we thus fix its position in the sky, at any given time and place.

69. The subject is illustrated by Fig. 19. Let A represent a place on the earth; Z, the zenith of the place where an observer is stationed; NEHRW, the circle of the horizon;[2] SZNM, the meridian circle; ZWEM, the prime vertical; B, a star, and ZBHMP, a vertical circle passing though the zenith and the star, B: all these circles being circles of the celestial sphere. Then the angle NAH, is the *azimuth;* EAH, the *amplitude;* BAH, the *altitude;* and ZAB, the *zenith distance* of the

1. For the meaning of the word *ecliptic*, see Art. 73.
2. It will be remembered that the planes of the sensible and rational horizons virtually meet at the distance of the fixed stars.

Show how we are to proceed according to the first method. What is meant by the terms azimuth, amplitude, altitude, and zenith distance. Show from the figure how these measurements of a star are taken

star, B. Had the star been situated at P, its amplitude and azimuth would have been reckoned from W, towards S, the *former* being the angle WAR, the *latter* SAR.

70. This method of determining the position of a heavenly body is, however, not sufficient for all astronomical purposes, since, inasmuch as every place on the globe has a *different horizon*, the azimuth, amplitude, altitude, and zenith distance of the same star, taken at any two places at the same absolute point of time, will not be alike. Astronomers have, therefore, devised a method of fixing the place of a star in the heavens, by measuring its distance from *two celestial circles, unchangeable* in position, whatever point the observer occupies upon the surface of the earth. These two circles are the *celestial equator*, and that *meridian* which passes through the centre of the sun in the spring, at the moment this centre is upon the celestial equator. This point of the celestial equator has received the appellation of the *vernal equinox.*[1]

71. DECLINATION AND RIGHT ASCENSION. The angular distance of a star, measured *from* the celestial equator, on a meridian passing through the star, is called its *declination*, and is termed north or south declination, according as the star is situated north or south of the equator. *Right ascension* is the distance of a star measured on the celestial equator in an easterly direction from the meridian passing through the vernal equinox. Right ascension may be reckoned either by angular measurement,[2] viz., degrees, minutes, and seconds, or by time,

1. *Ver*, the Latin word for spring; *equinox*, a word formed from two Latin words, *æquus*, equal, and *nox*, night. The vernal equinox is so called because when the sun appears at this point in the heavens, the nights, and consequently the days, are equal in length in every part of the world.

2. The following figure will enable the scholar to understand how angular measurements are taken. Let OCD be a portion of a brass circle, the arc of which, viz., OD, is divided into degrees and minutes. To the centre, C, a telescope, PL, is attached, movable on a pivot at C. Now, if the brass *arc* is held *vertically*, and the *edge*, CD, *horizontally*, and the observer,

Why is not the position of a star accurately fixed for all astronomical purposes when its azimuth and altitude are determined? What other mode of measurement has been devised by astronomers? What is understood by the term vernal equinox? What is declination? What is right ascension? How is it reckoned? Explain from *note* 2 how angular measurements are taken.

viz., hours, minutes, and seconds. For, since all the fixed stars in the heavens apparently revolve about the earth once every twenty-four hours, any star completes three hundred and sixty degrees of angular motion in that time; consequently it seems to move fifteen degrees every hour, fifteen minutes every minute of time, and fifteen seconds every second of time. So that a star which is situated on a meridian fifteen degrees east of the meridian passing through the vernal equinox, is said to have a right ascension of *fifteen* degrees, or of *one hour;* inasmuch as one hour elapses between the passage of the vernal equinox, and that of the star across the meridian of the place of the observer.

72. The subject is illustrated by Fig. 20, where P represents the north pole of the heavens, P♈[1] a celestial meridian passing through the vernal equinox, QAQ' the celestial equator, S the place of a star, PSA a part of a celestial meridian passing through the star, and C the centre of the celestial sphere; or what is the same in effect the place of the spectator.

Now the declination of the star is the arc SA, since this arc measures the angular distance of the star from the equator QAQ'. PSA, is one quarter of a meridian

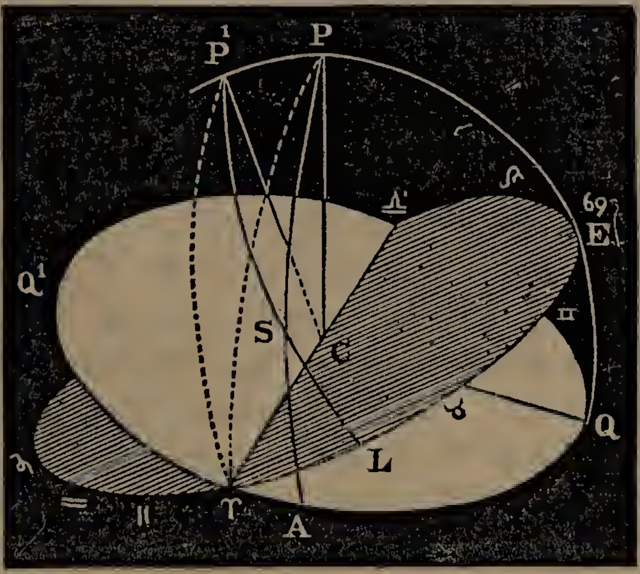
with his eye at P, then views a star in the direction PCLS, the angle measured on the arc DO, from D, viz., DCL, or HCS, will be the *altitude* of the star, S, above the horizon, H. In the figure it is fifteen degrees. If the brass arc is held *horizontally*, and the edge, CD, is in a line with the *meridian*, the angle SCH will be the *azimuth* of the star.

1. The character ♈ is called Aries and is that point in the celestial equator which is termed the *vernal equinox.* P♈ is read thus, *P, Aries.*

Show from figure what is the declination and right ascension of the star at S

passing through S, and contains *ninety degrees*, and if AS contain *forty degrees*, the *declination* of the star is *forty degrees north*. The *right ascension* of the star is ♈A,

FIG. 20



DECLINATION, RIGHT ASCENSION, LATITUDE, LONGITUDE.

and it this arc contains *fifteen degrees* the star at S has *fifteen degrees* of right ascension or *one hour*.

73. Ecliptic. The imaginary line that the earth describes in her annual progress around the sun is termed her orbit, and its position in regard to the celestial equator is ascertained by tracing the apparent path of the sun through the heavens, from day to day throughout the entire year. It differs somewhat from the form of a circle being an ellipse, and its plane passes through the centre of the earth and sun, having an inclination to that of the celestial equator of about 23° 27′. Its intersection with the celestial sphere is called the *ecliptic*[1]; and constitutes what may be regarded as a great circle of the heavens.

74. Latitude and Longitude. In addition to the two preceding methods of determining the position of the stars, a third has been adopted by referring them to

1. So called because eclipses happen in or near its plane.

What is meant by the earth's orbit. Is it a circle? What is the inclination of its plane to that of the celestial equator? What is the ecliptic? What is understood b the *Latitude* of a star? What by its *Longitude*. Explain from figure.

the *ecliptic*, and to a great circle passing through the *vernal equinox.* Thus, the angular distance of a star from the ecliptic measured on a great circle passing through the poles of the ecliptic, is called its *latitude*, and its angular distance measured on the ecliptic eastward, from the equinox whence right ascension is reckoned is termed its *longitude.* Thus, in Fig. 20, where ♈LE represents the ecliptic, P^1 its north pole, P^1♈ a great circle passing through Aries, and P^1SL, a great circle passing through the star at S, SL is the *latitude* of the star, that is, its distance *from the* ecliptic measured on the great circle P^1SL. Since the arc P^1SL is *ninety degrees*, if SL is *thirty degrees*, the *latitude* of the star is *thirty degrees* north. The *longitude* of the star is ♈L; the angular distance from Aries measured *on* the ecliptic to the great circle P^1SL passing through the star. If ♈L is *thirty-five* degrees, then the *longitude* of the star is *thirty-five* degrees.

75. THE SIGNS. The ecliptic is divided in twelve equal parts, called *signs*, each sign occupying in the heavens, an extent of thirty degrees; within these divisions, are situated certain conspicuous clusters of stars, termed *constellations*, which in the infancy of Astronomy, received particular names, and these names were also given to the signs. The following are the names and characters of the signs, *north of the celestial equator*, beginning at the vernal equinox,

ARIES, The Ram, ... ♈	CANCER, The Crab,........... ♋
TAURUS, The Bull,............ ♉	LEO, The Lion,................ ♌
GEMINI, The Twins,.......... ♊	VIRGO, The Virgin, ... ♍

The next six the names and characters of those south of the celestial equator,

LIBRA, The Scales, ... ♎	CAPRICORNUS, The Goat, ... ♑
SCORPIO, The Scorpion,....... ♏	AQUARIUS, The Water-Bearer, ♒
SAGITTARIUS, The Archer,... ♐	PISCES, The Fish,............. ♓

76. ZODIAC. The Zodiac is a belt of the celestial sphere extending eight degrees on each side of the eclip-

How is the ecliptic divided? What is the extent of each sign? What are situated within these divisions? Give the names of the signs? Which are north and which south of the celestial equator? What is the Zodiac, and why is it so called?

tic. It is so called from the Greek word *zodia* meaning *figures of animals* because they symbolize most of the signs of the ecliptic; also called the signs of the zodiac.

CHAPTER IV.

OF REFRACTION AND PARALLAX.

77. In the last chapter we explained the methods of determining the position of the heavenly bodies by measuring their angular distances from certain great circles of the sphere.

In order, however, that their places may be fixed with precision, *two* important corrections are necessary, *one* to be applied in the case of the *fixed stars*, and *both* when the bodies observed are comparatively *near* the *earth*, as for instance, the sun and moon. The question may be asked, why are these corrections indispensable? The reply is; First, that owing to the action of the atmosphere upon the rays of light, a star is seen *out of its true place* in every position but one; Secondly that a like displacement occurs when a body not very remote, as the moon for instance is observed at the same instant of time from *different* points of the *earth's surface.* The first displacement is caused by *refraction*[1] the second by *parallax.*[2]

78. Refraction. When a ray of light emanating from any object passes obliquely out of one medium[3]

1. ***Refraction.*** From the Latin ***refractus***, broken. The deviation of a line from its original course.

2. ***Parallax.*** From the Greek ***parallasso.*** To change one place for another.

3. ***Medium.*** This word here means ***any thing through which light passes.*** Thus if we look at a star the atmosphere is the medium through which we see it, and is so called because it is in the ***middle*** between the eye and the star. ***Medium*** is the Latin word for ***middle.***

What have been explained in the last Chapter? How many important corrections are necessary to fix with precision the place of a heavenly body? What effect has the atmosphere upon the rays of light? How is the second displacement caused? What is refraction? What parallax? Explain refraction.

into another of different density, it is refracted or bent out of its original course, and when it reaches the eye the object is seen in the *direction* of the *last refracted ray.*

In passing out of a *rarer* into a *denser* medium, the ray is turned towards the perpendicular to the surface of the medium; the latter being drawn through the point where the ray strikes the surface. Now the atmosphere is a transparent medium, enveloping the globe and gradually decreasing in density from the surface of the earth upwards; as the light from all celestial objects reaches us through this medium, it necessarily suffers refraction, and these radiant bodies are therefore seen by us as out of their true place.

The angular distance between the *true* and *apparent* place of a heavenly body, is its *astronomical refraction.*

79. Thus, if E, Fig. 21, represents the earth, Z the zenith, and 1, 2; 2, 3; 3, 4, different strata of the atmosphere, decreasing in density from 1 to 4, a ray of light proceeding from the star S, and meeting the exterior stratum of the atmosphere at 4, will be successively refracted in the directions 4, 3; 3, 2; 2, 1, towards the perpendiculars 4a, 3b, 2c; so that a spectator at 1 will not see the star S in its real position, at S, but *above* it in the direction 1 2 S^1. The angle $S1S^1$ is its *astronomical refraction.*

80. The direction of the ray in its passage through the air is constantly varying, since the density of the atmosphere changes by imperceptible degrees. Its course will not therefore be accurately represented by the broken line 4, 3, 2, 1, but by a curved line taking the same general direction passing through the points 4, 3, 2, 1, and concave to the surface of the earth.

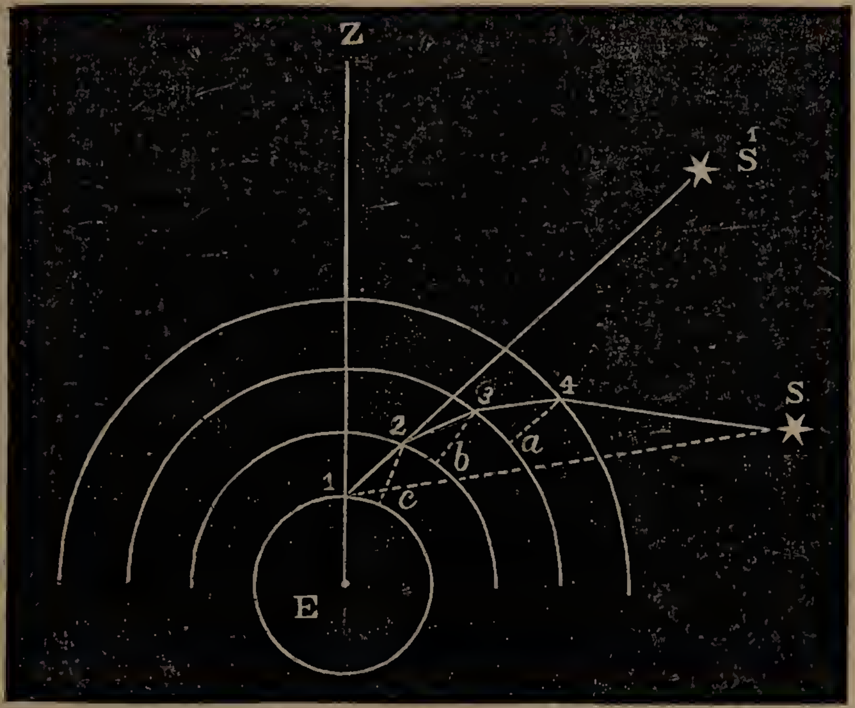
81. Variation of Refraction in respect to Altitude. When a ray of light passes out of one medium into another, the more *obliquely* it strikes the surface of the second medium the *more* it is *refracted*, and if it falls upon it *perpendicularly* the ray is *not refracted* at all.

82. Now the light from a star strikes the atmosphere at the greatest possible obliquity, when the luminary is

In what direction is an object seen. In passing out of a rarer into a denser medium, how is the ray bent? What is said respecting the atmosphere? What is Astronomical refraction. Explain from figure. Why is the course of the ray a curved and not a broken line? When is a ray of light most refracted? When not at all?

upon the horizon. This obliquity continually diminishes with the altitude. At the zenith it is nothing, for

FIG. 21.



REFRACTION.

the rays of a star in the zenith fall perpendicularly upon the atmosphere. The *refraction* is therefore *greatest at the horizon*, and constantly *decreases* with the *altitude*, until at the *zenith* it becomes *nothing*. The following table exhibits the amount of refraction at different altitudes.

APPARENT ALTITUDE OF THE RADIANT BODY BEING	THE AMOUNT OF REFRACTION IS
0 at the horizon,	33′ 50″
1°	24′ 25″
3°	14′ 35″
10°	5′ 20″
20°	2′ 39″
44°	1′
62°	31″
71°	20″
83°	7″
90° at the zenith,	0

It will be seen by a simple inspection of the table

In what position of a heavenly body are its rays most refracted? Where is it seen in its true place. Give the table of altitudes and corresponding refractions?

that the decrease of refraction is not by any means uniform, for the changes are extremely *rapid* near the *horizon* but proceed *very slowly* as we approach *the zenith.*

83. THE EFFECT OF REFRACTION ON THE POSITION F HEAVENLY BODIES. Refraction causes a body to be seen above its true place. Thus, in Figure 21, the observed star, if there was no refraction would be seen by the spectator in the direction 1 S; S being its true place, but owing to the refraction caused by the atmosphere, it is seen at S¹ nearer the zenith. It has therefore been elevated by refraction through the angular distance S1S¹ measured on a great circle perpendicular to the horizon. Refraction, therefore, *increases* the *altitude* of a heavenly body, or what is the same diminishes its zenith distance. The correction for refraction must therefore be *subtracted* from its *apparent altitude* in order to obtain the *true altitude.*

84. ON DECLINATION AND RIGHT ASCENSION. The displacement produced by refraction, affects the declination and right ascension of a heavenly body. If an observer stationed at the equator, were to take the altitude of any star on the meridian, either north or south of the zenith, on account of refraction the star would be seen *nearer* the celestial equator than it actually is. Its *declination* would therefore be *diminished.* If the star observed were in the *east* upon the celestial equator, refraction would carry it along the celestial equator *nearer* the *vernal equinox* than its real position, and would therefore *diminish* its right *ascension*, but if the star was in the *west* it would be carried by refraction *from* the vernal equinox, and thus its *right ascension* would be *increased.*

85. An observer at either pole of the earth would see the horizon coinciding with the celestial equator and at these stations, refraction would consequently *increase*

Are the changes in refraction from the horizon to the zenith uniform? Where are they most rapid? Where slowest? Is a heavenly body seen above or below its true place, when its light suffers refraction? Explain from figure How is the altitude of a heavenly body affected by refraction? What use must be made of the correction for refraction in order to obtain the true altitude? Explain in what manner the astronomical refraction of a heavenly body would affect its right ascension and declination at the equator; when on the meridian or the celestial equator? How at the poles?

the *declination* of every star in the visible heavens. Their right ascension would be unaffected.

In all latitudes from the equator to the poles, the displacement caused by refraction is in a direction *oblique* to the *celestial equator*, unless the heavenly body is in the meridian, it therefore affects with this exception both right ascension and declination, and the same is true in respect to the refraction of all stars observed at the equator, which are not situated either on the meridian or the celestial equator.[1]

86. The amount of refraction at the horizon is about thirty-four minutes, which is a little greater than the angular diameters of the sun and moon. At their rising and setting, therefore, these bodies come entirely into view when they are *actually below the horizon;* an extraordinary instance of refraction is said to have occurred in the year 1597, at Nova Zembla, in N. Lat. 75½°, the sun appearing above the horizon, when it was really *seven times* the length of its *apparent diameter below it.* The effect, therefore, of refraction upon the sun is to increase the length of the day.

87. This point is illustrated by Figure 22, where E represents the place of the observer on the earth, and S the *true position* of the sun when he appears just above the horizon H'H at S'. The ray LdE coming from the lower edge of the sun reaches the spectator at E in the direction dE, and he sees the lower edge in the direction of EdL'. In the same manner the ray Rd E, proceeding from the upper edge of the sun comes to the spectator in the direction d'E, and the upper edge is seen in the direction Ed'R'. Thus, the entire body of

1. This must be so, for a *displacement* which takes a direction *oblique* to the equator can be resolved by the laws of mechanics into *two* displacements, one of which takes place in a direction *parallel* to the equator, and the other perpendicularly *to* or *from* it. The *first* affects *right ascension*, the *second declination.*

How at all latitudes between the equator and the poles? How at the equator when the observed stars are neither in the meridian nor the celestial equator? How does the amount of refraction at the horizon compare with the angular diameters of the sun and moon? What singular phenomenon occurs at the rising and setting of the sun and moon? What extraordinary instance of refraction was once observed at Nova Zembla? What influence has refraction on the length of the day. Explain Figure 22.

the sun is actually seen above the horizon H'H, at S', when the orb is really below it at S.

FIG. 22.

EFFECT OF REFRACTION UPON THE SUN WHEN ON THE HORIZON.

88. All the other heavenly bodies are similarly affected, the time of their *rising* being *accelerated*, and that of their *setting retarded*. The period of the visibility of the stars above the horizon, is therefore increased by refraction.

89. Refraction influenced by the Temperature and Pressure of the Atmosphere. It has been found that the varying pressure and temperature of the atmosphere at the place of observation, produce a change upon the refraction for any given altitude. Astronomers for this reason in preparing tables of refractions for use, give due weight to the indications of the *thermometer* and *barometer*, in order to insure correctness in the results. Thus in the tables given in Art. 82. the estimates are made upon the supposition that the height of barometer[1] is *thirty inches*, and that the temperature is 47° Fah.

90. Of Parallax. The *apparent angular displacement* of a body caused by being seen from different points of observation is *its parallax*.

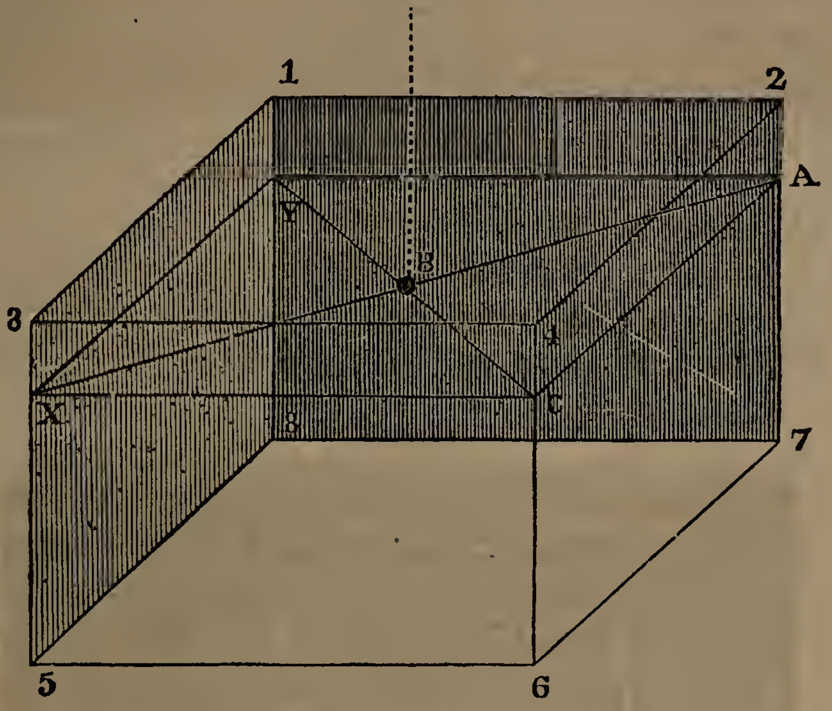
Thus, if two persons A and C, placed at two adjacent corners of a room were to look at a ball situated in the centre of the room, A would see it in a line with the opposite corner nearest to C, and C in the direction of the corner nearest to A; and the *angle* made by the two lines

1. The barometer is an instrument that measures the pressure of the atmosphere.

What effect has refraction on the rising and setting of all heavenly bodies? Does it lengthen or shorten the period of their visibility? Do the temperature and pressure of the atmosphere influence refraction? What is said respecting the construction of the tables in Art 82? What is parallax

of visible direction, would in a general sense be the *parallax* of the ball. Thus in Fig. 23, where the lines 1, 2; 2, 4; 2, 7; &c., represent the outline of the room, let B be the ball, A the place of the eye of one spectator, and C

FIG. 23.



PARALLAX EXPLAINED.

the position of that of the other. The ball would be seen by the first in the direction ABX, and by the second, in the direction CBY, and the angle ABC would be the *parallax* of the ball, or the *angular displacement* that it suffers by being viewed from the two stations A and C.

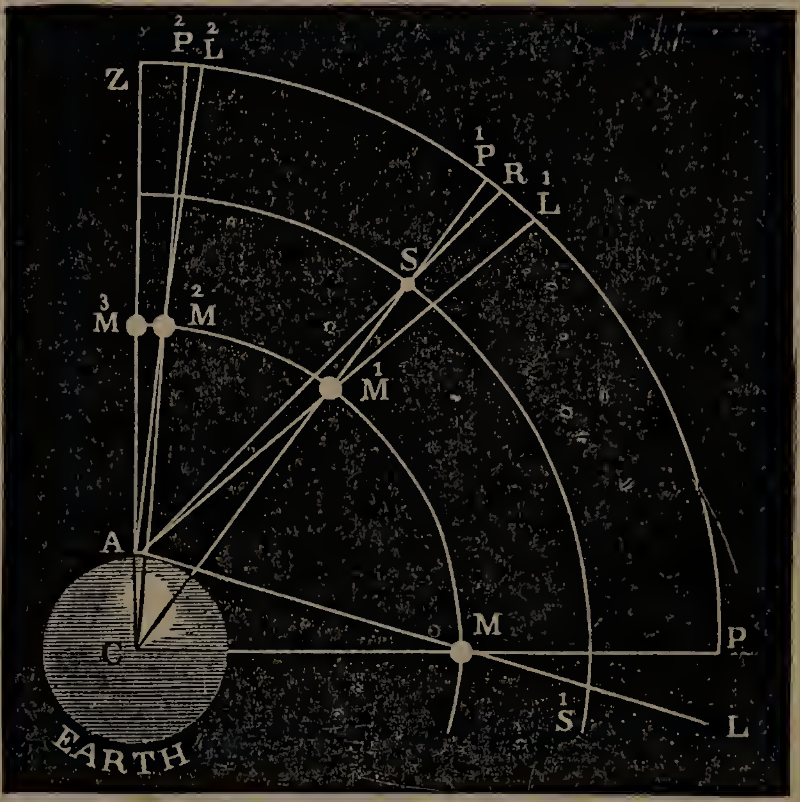
91. Now if two astronomers, one at St. Petersburg, and the other at the Cape of Good Hope, were to observe the moon at the same absolute moment of time, and fix her position in the heavens, making allowance for *refraction only*, it is evident that their results would not be exactly alike; because the two observers behold the moon from *different points* in *space*, and would see her in *different places* on the *celestial sphere;* and such would be the case with any observers who were not making their observations from the same spot.

Explain from figure. Relate what is said respecting the observations upon the moon taken from different stations? Why must allowance be made for parallax in astronomical observations?

Allowance must therefore be made for this angular displacement or parallax in order to prevent confusion in astronomical calculations; and as in the case of longitude we must have some standard meridian whence to reckon the degrees of longitude, so in parallax we must have some *standard station*, from which all celestial objects are supposed to be viewed. This imaginary station is the *centre of the earth*, and the true position in the sky of any heavenly body, is determined by an imaginary line drawn from the *centre of the earth to the centre of the body*, and prolonged to meet the starry vault.

92. Parallax. How measured. The angle contained between two lines, drawn from the centre of the body, *one* to the *eye of the observer*, and the *other* to the

FIG. 24.



PARALLAX OF A HEAVENLY BODY.

centre of the earth, is the measure of the parallax of the body.

Thus, in Figure 24, where the curve PRZC represents

Where is the standard station from which all celestial objects are supposed to be seen? How is the true position in the heavens of a planet or planetary body determined? How is parallax measured? Explain from figure.

a fourth part of a celestial circle extending from the horizon P to the zenith Z, M, M^1, M^2, M^3 the *moon* at different altitudes, C, the centre of the earth, and A the place of the observer; AMC is the angle of parallax when the moon is in the horizon, AM^1C, the same when she is fifty-five degrees above the horizon, and AM^2C when she is near the zenith.

93. VARIATIONS IN PARALLAX—EFFECT OF ALTITUDE. It is evident from the inspection of the figure where the arc M, M^1, M^2, M^3, M^2 represents a part of the moon's orbit that the parallax is *greatest* when the moon is on the *horizon*, and gradually *diminishes* until it becomes nothing at the *zenith*. At the zenith there can be no parallax, because the lines drawn from the centre of the moon at M^3 to the place of the observer at A, and to the centre of the earth C, make no angle with each other but form one line; the moon must therefore be seen at the *same place* in the starry heavens; viz. Z, whether viewed from A or C.

What has been just stated in respect to the moon is true also of every other heavenly body, whose parallax can be measured; viz., that the parallax is greatest when the body is at the horizon, and gradually diminishes with the altitude, becoming nothing at the zenith.

94. HORIZONTAL PARALLAX. The *horizontal parallax* of a body is its parallax when *seen upon the horizon.* Thus, in Fig. 24, the observer being at A, the horizontal parallax of the moon is the *angle* AMC; an angle formed by drawing from the centre of the body whose parallax is sought *two lines*, *one* to the place of the *spectator touching the* earth, and the other to the *centre* of the *earth.*

95. EFFECT OF DISTANCE. The amount of parallax is influenced by distance; the *greater* the *distance* the *less* the *parallax*, and the *smaller* the *distance* the *greater* the *parallax*[1]. This is clear from a glance at Fig. 24, where

1. When this relation exists between two quantities they are said to be *inversely proportional to each other.*

When is the parallax greatest? When does it become nothing? Why does it? What is horizontal parallax? Explain from figure. Are the statements just made applicable to every other heavenly body having a parallax that can be measured? Is the amount of parallax influenced by the distance of a body? Give the rule.

S represents a planet more distant from the earth then the moon at M^1, but having the same altitude; and SS the path of the planet. Now the parallax of the planet S is the angle ASC which is evidently smaller than the angle AM^1C, which is the parallax of the moon at M^1.

96. Since the parallax decreases with the increase of distance, it results that when a body as a fixed star is situated very far from the earth the parallax becomes so small that it is impossible to measure it; a fixed star will therefore appear to occupy the same place in the heavens, whether viewed from the centre or the surface of the earth; indeed the same will be true if it is even observed from opposite sides of the earth's orbit around the sun.

97. Effect of Parallax upon the true position of a Heavenly Body. The true position of a heavenly body, being that which it would have if seen from the centre of the earth, it is evident that the effect of parallax is to *depress* a body below its true position. In Figure 24, the true position of M, in the celestial vault is P, since it would appear at P if the eye was at C; but the spectator at A, sees the moon at the place L in the celestial vault, the luminary being depressed, the extent of the arc of parallax PL. The amount of depression at M^1 is P^1L^1, and at M^2 it is P^2L^2.

We thus see that parallax *decreases* the *altitude* of a heavenly body, and must therefore be added to the *apparent* altitude, in order to obtain the *true altitude.*

98. On Declination and Right Ascension. At the poles of the earth the effect of parallax, to its whole extent, would be to *lessen* the *declination* of a heavenly body, since it would cause it to appear *nearer* the *celestial equator* (which here coincides with the horizon) than its true position. At the equator of the earth the entire influence of parallax, if the body was in the *east* would be to *increase* its right ascension, and if in the *west* to *diminish* it. If it was on the *meridian* the *declination*

Explain from figure. What is said of the parallax of the fixed stars? What is the effect of parallax upon the true position of a heavenly body? Explain from figure. What effect has parallax upon the altitude, and how must the correction for altitude be employed? What is the effect of parallax upon declination and right ascension? At the poles?

only would be *increased*, but in all other directions not named, parallax would influence both right ascension and declination. At all latitudes between the poles and the equator, right ascension and declination would likewise be both influenced by parallax, except when the body was in the meridian when the declination only would be affected. In a word, the displacement caused by parallax in regard to altitude, right ascension, and declination, is exactly the *reverse* in direction to that which happens from refraction, and which has already been explained.

99. PARALLAX—ITS VALUE. The determination of the amount of parallax belonging severally to distant heavenly bodies is of the utmost importance in astronomical researches. By its aid we can ascertain the distances of the sun, planets, and comets; and knowing their distances we can tell their actual magnitudes, their densities and the quantity of matter they separately contain, together with the extent of their orbits, and the swiftness of their speed.

Still further, having by means of the parallax of the sun obtained his distance from the earth, this distance becomes the *measure* by which the astronomer gauges the remoter heavens, and discovers the amazing distances of the fixed stars. Without the key afforded by parallax his efforts would be checked at the beginning, and a vast field of knowledge would remain forever unexplored.

100. More mathematical knowledge is required to understand the method by which the parallax of a body is ascertained, than the majority of students for whom the work is prepared are expected to possess.

For the benefit of those who have a knowledge of Trigonometry, the following demonstration is annexed. Let C be the centre of the earth, PP^1 a portion of the terrestrial meridian passing through the stations of two observers, one at P, the other at P^1. ZL^1OLZ^1 the corresponding celestial meridian, Z the zenith of the observer at P and Z^1 the zenith of the observer at P^1. M represents the moon, L the place in the heavens at which she is seen by the observer at P, and L^1, her place as beheld from P^1, her true place being O the direction in which she is seen from the centre of the earth. Now to find the parallax at P, viz.,

At the equator and at intermediate latitudes? Compare the effects of refraction and parallax in the above particulars? Why is the knowledge of parallax important to the astronomer?

CHAPTER V.

OF THE MEASUREMENT OF TIME.

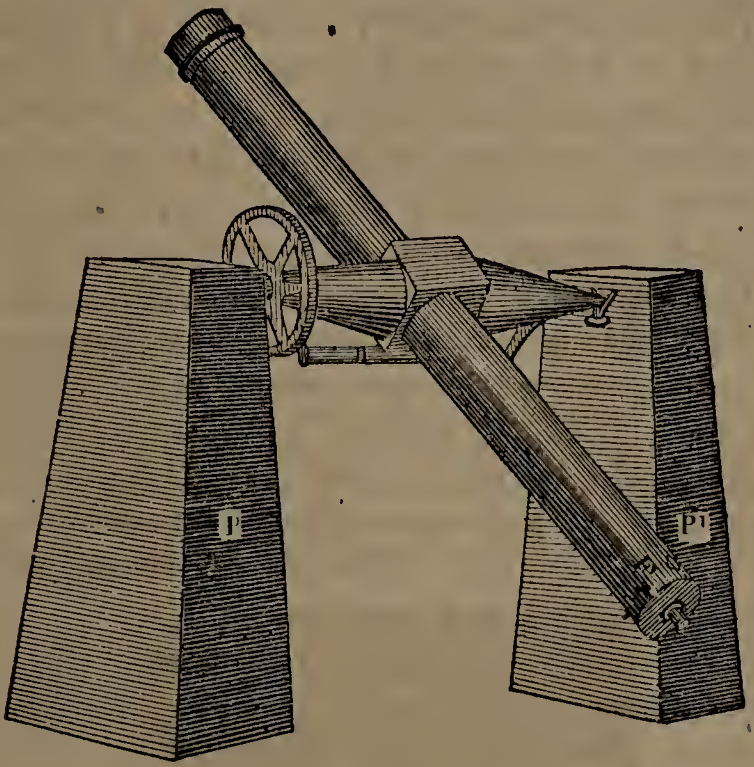
101. Transit Instrument. Having now acquired a knowledge of the circles of the celestial sphere, and the manner of fixing the positions of celestial bodies in the sky, we are prepared to investigate more minutely the *rotation of the earth on its axis.* We have discovered the *fact* of the rotation, but h ,ve not yet ascertained whether the earth moves *faster* at one time than at another. This point, however, is readily ascertained by the

CMP. Taking the figure as drawn, we have first, the latitudes of the two stations which gives us the angle PCP^1, consequently in the isosceles triangle P^1CP we have the two lines PC, P^1C, each a radius of the earth, and the included angle to find the other angles and the side PP^1. Now the zenith distances of the moon, as seen from both stations, can be measured;

tney are the angles ZPL and $Z^1P^1L^1$; therefore we know their supplements to wit, LPC and L^1P^1C. Taking away from these respectively, the angles CPP^1 and CP^1P, we have remaining the angles LPP^1 and L^1P^1P. Consequently in the triangle MP^1P we have the side PP^1, and all the angles to find the other two sides MP and MP^1. Now taking the triangle MPC we have the side MP (just found) CP a radius of the earth, and the angle M PC the supplement of the moon's zenith distance, to find the other parts one of which namely CMP is the parallax. In this manner the parallax of Mars, was obtained by Lacaille and Wargentin, the former being stationed at the Cape of Good Hope, the latter at Stockholm. If the parallax at any altitude is obtained, the horizontal parallax can be derived from it; the parallax varying as the sine of the zenith distances. This method is not exact enough for the sun, owing to his great distance. His true horizontal parallax is otherwise found, (Arts. 462–3,) and his distance is then computed by it.

aid of an *accurate* clock, and a peculiar kind of telescope called a *transit instrument* Fig. 25; within this instrument is placed a system of wires like those shown at *ac*,

FIG. 25.



TRANSIT INSTRUMENT.

Fig. 26, one horizontal and five vertical: the latter being parallel to each other, and separated by equal intervals;[1]

FIG. 26.

WIRES.

1. See note 1, to Art. 103.

Of what does Chapter IV treat? How can we ascertain that the earth moves uniformly on her axis? Describe the transit instrument?

1, 2; 2, 3; 3, 4; &c. These wires are situated in the focus[1] of the eye-glass at F, Fig. 25, their plane being at right angles to the imaginary line[2] passing lengthwise through the centre of the telescope, the central vertical wire C, cutting this line at right angles.

102. The telescope is provided with a horizontal axis upon which it rests, and it must be so adjusted, when properly arranged, that the *central* wire shall move with perfect accuracy in the *plane of the meridian*, as the instrument revolves on its points of support. This is the great object sought in its adjustment, and to guard against the slightest deviation, the pillars, P, P[1], upon which the ends of the horizontal axis rest, are built of the firmest masonry, and detached from the other parts of the building where the transit instrument is placed, so that they may not be affected by any motion of the edifice. Levels are attached to the instrument to aid in its adjustment. Measurements are taken upon a graduated circle[3] fixed to the axis.

103. Of the Time Occupied by the Earth in Performing one Rotation.—How Determined. Let us now observe the astronomer as he proceeds to investigate the problem of the earth's rotation on her axis. Seated in his observatory, with his telescope and clock properly adjusted, he selects for his sky-mark some bright fixed star near the meridian. He watches it closely, and soon the earth, as it rotates towards the east, brings the telescope *up to* the star. At the moment the latter is upon the meridian, the middle vertical wire of the instrument cuts the star exactly in two, and the astronomer notes the time by his astronomical clock; we will suppose it to be eight. During the rest of the night and the succeeding day, the astronomer, with his obser-

1. The focus is that place in front of the eye-glass, where the wires can be seen distinctly, when a person is looking through the telescope.

2. This line is called the line of *collimation*, and is imagined to join the centres of the object and eye-glasses.

3. A graduated circle is a metallic circle, the *circumference* of which is divided into *degrees*, *minutes*, and *fractions of a minute*.

What is the great object sought in the adjustment of the transit instrument? How are measurements taken? Describe in full how the time occupied by the earth in performing one rotation is determined

vatory and instruments rotating with the earth, passes star after star in succession, and as eight o'clock approaches, the observed star of the preceding evening is seen again near the meridian. The astronomer is at his post, and again the central vertical wire[1] cuts the star exactly in two, showing that the earth has *completed one rotation;* and at this identical moment the clock indicates with the utmost precision the hour of eight. *Twenty-four* hours have elapsed since the first observation; this then is the period of time occupied by the earth in performing *one entire rotation.* Such observations have been made repeatedly, both upon the same star and upon different stars, and at stations widely separated, and the result has been found to be *invariably* the same. Centuries may intervene between two series of observations, and yet the results are identical; we thus arrive at the conclusion that the *interval of time* elapsing between two *successive transits*[2] *of a fixed star*, and which measures *one entire revolution* of the earth, is *unchangeably the same.*

104. Having found that the earth rotates once every twenty-four hours, a question arises, is this motion uniform? That is, does the earth rotate through *equal spaces* in *equal times*, performing half a rotation in twelve hours, a quarter in six hours, and so on? This is found to be the case. If the angular distance between two stars is *fifteen* degrees, or one twenty-fourth part of one entire rotation, i. e., *three hundred and sixty degrees;* the time that elapses from the transit of the first star to the transit of the second, is exactly *one hour*, no matter at what time of the day the observations are taken. The earth, therefore, passes through *one twenty-fourth*

1. To avoid errors, the astronomer marks the time when the star crosses each of the five vertical wires, and then, by taking an average of these times he can determine with greater precision *when* the centre of the star is in the meridian, than if he noted its passage only across the central wire.

2. ***Transit.*** The transit of a star is the moment of its passage across the meridian when it is cut exactly through the centre by the central vertical wire of the transit instrument. Transit, from the Latin word *transitus*, a passage.

Is this period changeable? Is the motion of the earth on its axis uniform? How is it proved?

part of a *rotation* in one *twenty-fourth* part of a *day*, and this is true for all other divisions, whether greater or smaller. Half of a rotation is performed in half a day, the one hundredth part of a rotation in the one hundredth part of a day, and so on.

105. STANDARD UNIT OF TIME. The period of the earth's rotation on its axis is the universally acknowledged unit of time, since it is the only natural marked division of time which continues unaltered from age to age. All other periodical motions of the heavenly bodies are subject to change, but the difference in the length of the natural day, as determined by a comparison of the earliest and the latest observations, is *inappreciable.* The different periods of time in common use all date from this. Weeks, months, and years are reckoned by days and fractions of a day, while hours, minutes, and seconds, are divisions and sub-divisions of the day.

106. OF THE SIDEREAL AND SOLAR DAY. The *sidereal*[1] *day* is the length of time that elapses between two successive transits of the *same fixed star* across the meridian, in other words, the period of the earth's rotation. The *solar*[2] *day* is the time that elapses at any place between two successive transits of the *sun* across the meridian of that place; or, as it is commonly expressed, the time that intervenes between *noon* of one day and *noon* of the next. The solar day is about *four minutes* longer than the sidereal, and the causes of this difference we will now proceed to explain.

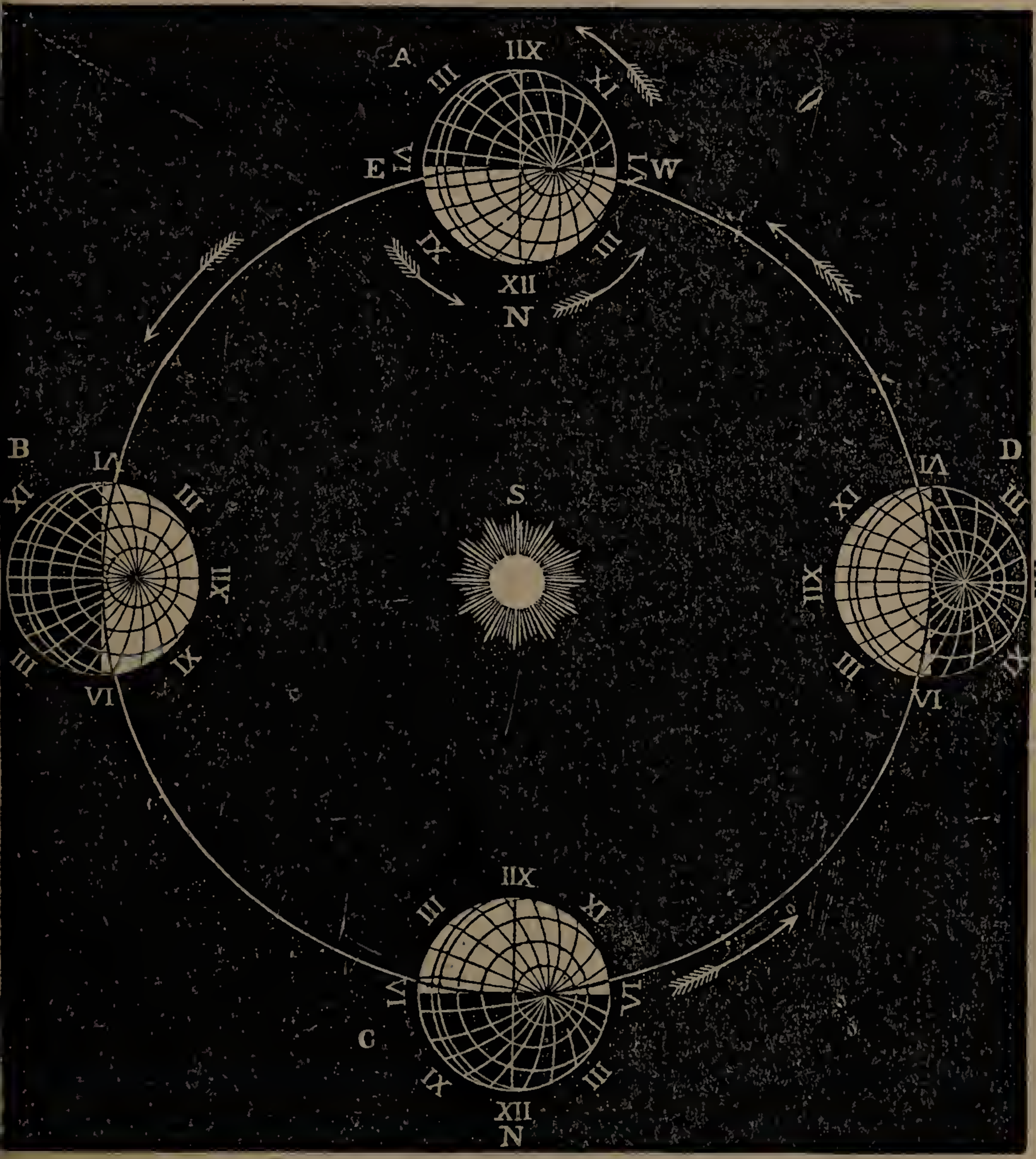
107. We must bear in mind; *First*, that the earth *moves around the sun* from *west to east*, rotating also at the same time on its axis from west to east. *Secondly*, that the *axis never changes its direction*, but constantly points north and south. *Thirdly*, that the *half of the earth* which *faces* the sun is *illuminated*, while the other is veiled in darkness. These facts are illustrated in

1. ***Sidereal***, from ***sidera***, the Latin word for stars.
2. ***Solar***, from ***Sol***, the Latin word for the sun.

What is the standard of time? Why is this division of time adopted as a standard? What is said of weeks, months, and years? Hours, minutes, and seconds? What is meant by the term *sidereal day*? What by *solar day*? Which is the longest? What is now to be explained? What three things must we bear in mind?

Fig. 27, where S represents the sun, and the globes, A, B, C, and D, four positions of the earth, three months apart; viz., at the *vernal equinox*, (A,) the *summer solstice*,

FIG. 27



SOLAR AND SIDEREAL DAY.

(B), the *autumnal equinox*, (C), and the *winter solstice*[1], (D). Here, in the *first place*, the earth is seen, as shown

1. The ***vernal equinox*** occurs on the 20th of March; the ***summer solstice*** on the 21st of June; the ***autumnal equinox***, on the 23d of September; and the ***winter solstice***, on the 21st of December.

by the arrows, rotating from west to east,[1] (W to E,) while at the same time it revolves about the sun in the like direction. *Secondly*, its axis is unchanged in position, as shown by the way in which the meridians converge. *Thirdly*, the hemisphere towards the sun is illuminated while the other is in darkness.

108. Now it is *noon* at *any place* when an imaginary plane, called the *meridian plane*, passing through the centre of the sun, and the north and south poles of the earth, also passes through this given place, dividing the *illuminated hemisphere* into *two equal parts*. And this must be the case, for the place has enjoyed the sunshine during the time the earth, in its daily revolution, has been describing the half of the illuminated part *towards the east*, and will enjoy it for the same space of time while describing the half *towards the west*. Thus, the earth being at A, it is *noon*, or twelve o'clock, at the place, N, which is in the position just described. For the time the earth occupied in revolving from the position E, to that of N, constitutes the half of the day[2] from *sunrise* to *noon*, while that employed in rotating from the position N, to that of W, is that half which is included between *noon* and *sunset*. As the earth is here at the vernal equinox, each half day is six hours long.

109. We will now suppose that it is noon at N, on the day of the vernal equinox; to-morrow, when the earth has exactly completed one rotation, it will not be noon at N, because the earth has advanced in her path around the sun about *one degree* from the vernal equinox. This orbitual motion[3] has caused the boundaries of the illuminated hemisphere to *shift around* to the ***east***, through nearly one degree, and the *meridian plane* has also moved ***eastward*** to the same extent. The earth must, therefore, rotate *over* and *above one entire revolution* through the same angular space of *nearly one degree*

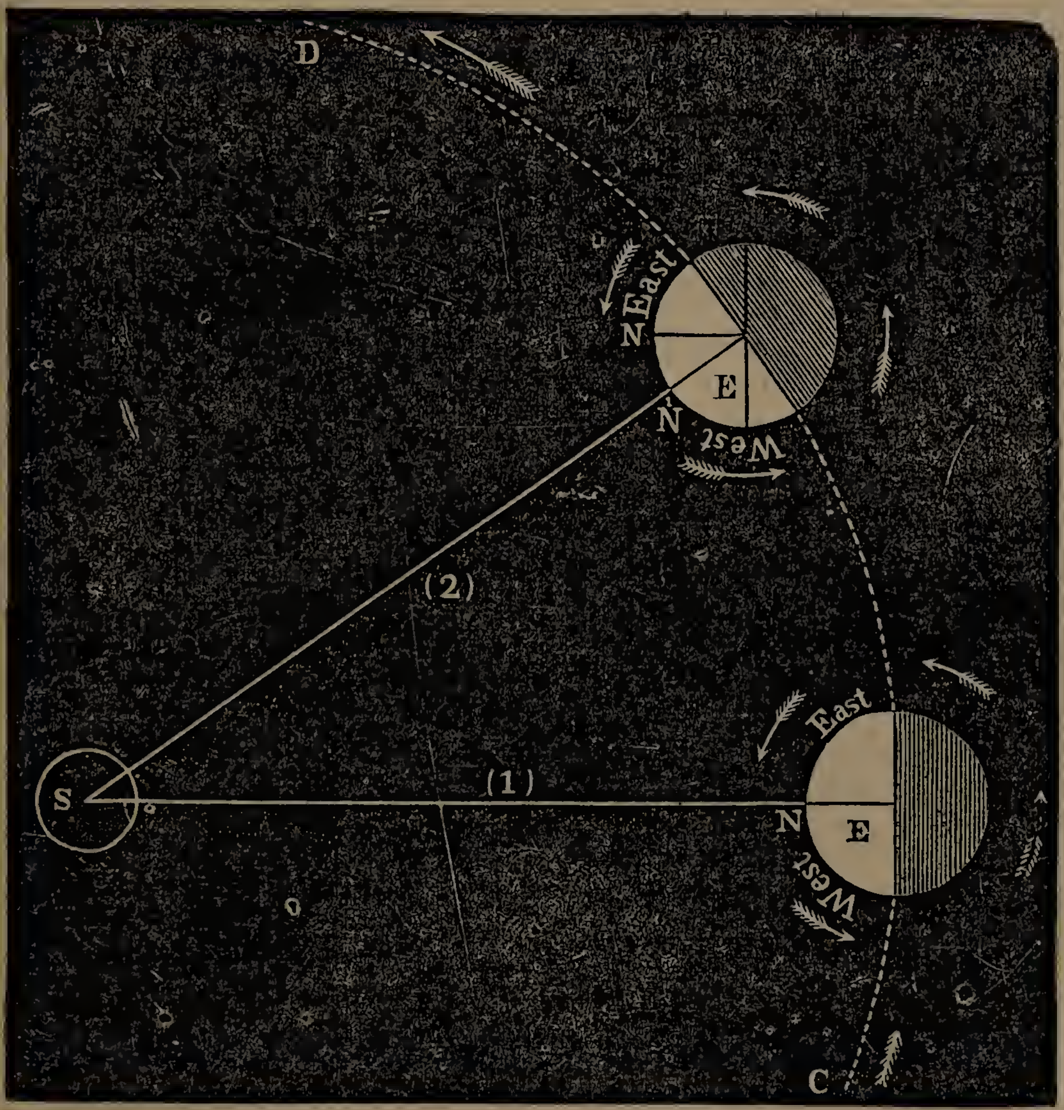
1. For an explanation of the term, ***rotating from west to east***, see Art. 134.
2. The word ***day*** is here used as opposed to night.
3. ***Orbitual motion***, motion in her orbit around the sun.

Illustrate by the figure. When is it noon at any place? Why so? Explain from Fig. 27. Why is the solar day longer than the sidereal?

before it brings the place N, into such a position that equal portions of the illuminated hemisphere will be immediately east and west of it. Then, and only then, has N reached the meridian plane, and the time of *noon arrived.* As the earth revolves through three hundred and sixty degrees in twenty-four hours, it passes through one degree in four minutes, so that in round numbers we may say that the *solar day* is about *four minutes* longer than the *sidereal.*

110. This subject is illustrated by the following diagram, Fig. 28, where S represents the sun, and E, E,

FIG. 28.



SOLAR AND SIDEREAL DAY.

How much longer is it? Explain from Fig. 28.

the earth in two positions of its orbit; the *dark* semi-circles are sections of the unenlightened hemispheres, and the *light* semi-circles, sections of the enlightened hemispheres. In *position* 1, it is *noon* at N, because there are equal portions of the illumined hemisphere on the east and west side of it. But on the next day, when the earth has made one complete rotation, and has in the meanwhile also moved along in its orbit, CD, to *position* 2, it will *not* then be *noon* at N, for the *meridian plane* now passes through N^1: the earth will have to revolve on its axis until N has arrived in the position N^1, before it will be noon at N, and the time occupied in describing the arc, NN^1, will be the *excess* of the solar above the sidereal day.

111. The difference in the length of the solar and sidereal day may be explained by the motions of the hands of a watch. Calling the time made by *one revolution* of the minute hand a *sidereal day*, a *solar day* may be compared to the extent of time that elapses from the instant the *hour* and *minute hands* are *together*, to the *next time* they are again in that position; a period manifestly longer than the first, since the minute hand has not only to make one revolution, but must also catch up with the hour hand, which has all the while been advancing.

112. Another view may be taken of this subject. A glance at Fig. 27 shows us, that reckoning from A the limits of the illuminated hemisphere at the summer solstice have shifted round along the plane of the ecliptic *one quarter* of a circumference, at the autumnal equinox *one half* a circumference, at the winter solstice, *three quarters* of a circumference; and when the earth has arrived at the vernal equinox again, the bounding circle dividing the illuminated from the unilluminated hemisphere, has made *one entire revolution;* the meridian plane changing round in the same manner.

113. Now, if we could imagine that on the day of the vernal equinox, just before it is noon at N, the earth

Explain the difference between solar and sidereal time. Illustrate by the motions of the hands of a watch. Illustrate the subject still farther by the aid of Fig. 27.

could be at once transported to the position it occupies at the autumnal equinox, (C) the place N, would be instantaneously buried in the gloom of midnight; since the limits of the illuminated hemisphere, and the meridian plane, would shift round half a circumference, and the earth would have to make almost half a rotation before N would again enjoy noon. So that the interval between noon on the day before the vernal equinox, and the noon of the day after, would, on this supposition, be very nearly *thirty-six* hours. But the earth makes no such rapid transition in passing from the vernal to the autumnal equinox, but occupies about one hundred and eighty-six days[1] in this journey; the bounding circle of the illuminated hemisphere and the meridian plane moving a little round every day, and completing *half a circumference*, in *circular motion* or *twelve hours* of *time* (one hundred and eighty degrees,) in the course of nearly one hundred and eighty-six days.

This daily motion of the meridian plane is, therefore, about *one degree*,[2] or nearly four *minutes of time*,[3] and constitutes the *excess* of the solar above the sidereal day.

114. Inequality in the Length of the Solar Days. In the previous explanations we have considered, for the sake of simplicity, that the solar days are of equal length, in other words, that the period of time comprised between noon of any one day, and noon of the next, is the same in every part of the year. But this is not so, for *two reasons*.

1. ***One hundred and eighty-six*** days, ***more nearly*** one hundred and eighty-six and a half. The earth occupies only about one hundred and seventy-eight and a half days in passing from the ***autumnal*** to the ***vernal*** equinox.

2. ***About one degree.*** 180° equals 10,800′ which, divided by 186 give 58′ or nearly one degree. The entire orbit of the earth, equal to three hundred and sixty degrees, is described in about three hundred and sixty-five days. The average daily angular motion throughout the whole year is found by dividing 360° equal to 21,600′ by 365, which give ***fifty-nine minutes***, and a little over.

3. ***Four minutes in time.*** This is obtained by dividing twelve hours by one hundred and eighty-six, which give nearly one-fifteenth of an hour, or four minutes.

Are the solar days of equal length? State the first cause of their inequality.

115. *First*, because the earth, not being always at the same distance from the sun, moves in different parts of its orbit with unequal velocities—advancing *most rapidly* when it is *nearest* the sun, and with its *least velocity* when *most remote* from this luminary. Consequently, the daily amount of change in the position of the meridian plane is *variable* throughout the year, and, therefore, the space of time which the earth must rotate, in order to complete a solar day, will also be variable. The *greatest difference* in length between the solar and sidereal day, is *two hundred and sixty-six seconds; the least two hundred and fifteen seconds;* and the *average* for the year, *two hundred and thirty-six seconds*, or *nearly four minutes.*

116. *Secondly*, time is not *reckoned* on the ecliptic, but on the *equator*, and since the plane of the former is inclined to that of the latter, it follows that any given angular motion of the earth along the ecliptic does not always give the same amount of angular motion on the equator. In other words, a *degree* of *longitude* is not *necessarily equal* to a *degree* of *right ascension.*

117. This is evident from the inspection of Fig. 29, where C represents the position of the earth at the vernal equinox; N and S the north and south poles of the earth, MCB the equator, L the sun, and RCOZ a part of the earth's orbit. CO is an arc of *longitude*, of *nineteen degrees* extent, which the earth describes in passing in its orbit from C to O, and CM is the corresponding[1] motion of the earth in *right ascension*, described in the *same time.* Now it is evident that CO is longer than CM,[1] consequently, when the earth has moved nineteen degrees in longitude from the vernal equinox, it has moved *less than nineteen* degrees in *right*

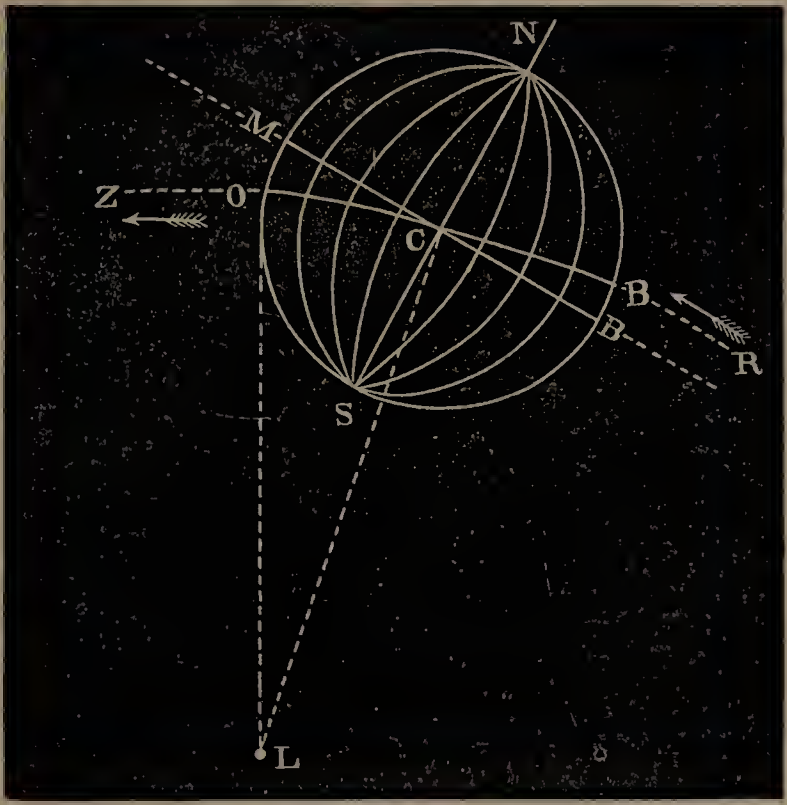
1. Arcs of longitude and right ascension are said to *correspond* when they are included between the planes of the same meridians.

2. *CO longer than CM*—because CMO is a right-angled spherical triangle, CMO being the right angle, and the side *opposite* the *right angle*, in a right-angled triangle, is *always greater* than either of the other sides.

What is the greatest difference in length between the solar and sidereal day? What the least? What the average? State the second cause of the unequal lengths of the solar days. Explain from figure. State what is said respecting arcs of longitude and their corresponding arc of right ascension.

FIG. 29.

EAST



WEST.

TIME RECKONED ON THE EQUATOR.

ascension; the same is here true of the *daily* arcs of *longitude*, and their *corresponding* arcs of *right ascension.*

118. From each equinox towards the next solstice, the *daily* arcs of longitude are at first *greater* than the corresponding arcs of right ascension; then *equal;* then *less.* And onward towards the next succeeding equinox, the daily arcs of longitude differ from the corresponding arcs of right ascension. These variations necessarily produce corresponding *changes* in the *length* of the *solar day.* They are independent of those arising from the first mentioned cause, for they would exist, even though the earth moved in every part of her orbit with the same speed.

119. MODES OF RECKONING TIME. The exigencies of society, and the refined calculations of science, have made it necessary that different modes of computing time should be adopted. Thus, we speak of *apparent*

What is the effect of these variations? Would the length of the solar day be influenced these if the earth moved uniformly in her orbit?

time, *mean solar time*,[1] or *civil time*,[2] and *astronomical time.*

120. APPARENT TIME is the time computed from *noon to noon* by the successive returns of any place to its meridian. Since these successive periods (as we have seen) are of variable length, the apparent solar days, which are nothing but these successive periods, are also of unequal duration.

121. MEAN SOLAR TIME is an arbitrary division of time, in which all the solar days are supposed to be of the same length, this length being found by dividing the whole amount of time in a solar year by the number of solar days in that period. Days of changing length would furnish an inconvenient method of reckoning for mankind, mean solar time is therefore employed in the common affairs of life, and constitutes *civil time.* Under this usage, the *mean solar day* is made to *consist* of *twenty-four* hours, in order to avoid a fractional expression for its length, which would happen if the sidereal day was divided into twenty-four hours. To compensate for this change, the latter is proportionally reduced in length. According to civil time the length of the mean solar day is, therefore, twenty-four hours, and that of the *sidereal*, *twenty-three* hours, *fifty-six minutes* and *four seconds.* The civil day commences at *twelve o'clock at night*, and is divided into two periods, of twelve hours each, *reckoning* from *one to twelve* from *midnight* to *noon*, and *again* from *one* to *twelve* from *noon* to *midnight.*

122. ASTRONOMICAL TIME is apparent time, and is employed for scientific purposes. The astronomical day *commences* at *noon*, and *terminates* at *noon* on the *next*

1. ***Mean Solar Time.*** The word ***mean*** here signifies ***average.***
2. ***Civil Time.*** The ***legal*** time or that appointed by a government to to be used in their dominions.

What is apparent time? What is mean solar time? What is civil time? Why is mean solar time adopted as civil time? Under this usage, of how many hours does the mean solar day consist, and why? What is the length of the sidereal day, that of the solar being reckoned at twenty-four hours? When does the civil day begin, and how is it divided? What is astronomical time? When does the astronomical day begin? Of how many hours does it consist, and how is it reckoned?

day. It consists of twenty-four hours, the hours being counted from one to twenty-four.

123. EQUATION OF TIME. The kind of time employed by mankind for regulating the common concerns of life is, as we have stated, mean solar time, in which all the solar days are considered to be of equal length. The period of a day is artificially determined by clocks and watches, and they are usually made to keep mean time. Were such a clock to move with perfect accuracy, all the days of the year, as indicated by it, would be exactly of the same length. The length of the true solar day varies throughout the year, being sometimes greater, sometimes less than the solar day, and at certain periods equal to it. The difference between the length of the true solar day and the mean solar day at any time of the year, is the *equation*[1] *of time* for that date.

124. If two clocks were taken, one of which kept true solar time, and the other true mean time, they would agree only on *four days* of the year, namely, April 15th, June 14th, September 1st, and December 24th, at which times it would be noon by one of the clocks at the same moment it would be noon by the other; throughout the rest of the year they would differ. Sometimes the true solar clock would be in advance of the other, and the sun would be said to be *fast of the clock*, and sometimes it would be behind, when the sun would be said to be *slow of the clock.* The difference in time between two such clocks at any period, would be the equation of time.

125. The equation of time subtracted from the solar time, when in advance of mean time, and added when behind it, gives the true mean time. Thus, on the 4th of July, 1852, the sun was slower than the clock by four minutes and four seconds, and this amount must be added

1. Equation, *a making equal.* Equation of time is so called, because when this quantity is added to, or subtracted from the true solar day, as the case may be, it makes it equal to the corresponding mean solar day.

How is the period of a day artificially determined? What kind of time do they keep? If a clock moved with perfect accuracy, how would the lengths of all the days of the year; as indicated by it, compare with each other? What is meant by the term equation of time? Give the illustration. The equation of time and the solar time being known how is the true mean time obtained? Give examples.

to the solar time to make it equal to the mean time, at that date; while on the 27th of November of the same year, the sun was in advance of the clock, twelve minutes and two seconds, and this quantity must be subtracted from the solar time to obtain the mean time on the given day. The equation of time is greatest on the 3d of November, when it amounts to nearly *sixteen minutes* and *eighteen seconds.*

126. This subject of the equation of time may be further familiarly illustrated by supposing that we have three hundred and sixty-five bullets, of nearly the same size, the weight of each bullet representing the length of a true solar day. Four of the bullets weigh two ounces each, while the rest are either lighter or heavier, but the weight of the entire three hundred and sixty-five bullets is seven hundred and thirty ounces, so that the average weight of a bullet is two ounces. Now the weight, two ounces, represents the length of a mean solar day, and if a person were to take up each of these bullets and in succession weigh them, the difference between the weight of each bullet and two ounces would represent the equation of time. In the prosecution of his task, he would find that some bullets would weigh less than two ounces, and then the difference must be added to obtain the mean weight of two ounces; again, others would weigh more, and it then would be necessary to subtract the difference to obtain the average weight. Four bullets, according to the supposition, would weigh exactly two ounces, and these would represent the days above mentioned, when the true solar and mean time exactly coincide. In this illustration we have not supposed, (as we might have done,) that the differences in weight vary according to the same order and extent as the equations of time, nor that the four two-ounce bullets have the same relative positions among the entire number of bullets as the four above mentioned days have among all the days of the year, nor was it necessary in the explanation of the point before us.

127. The four epochs of the year when the true solar

At what time of the year is the equation of time greatest? Give the illustration in Art. 126.

time agrees with the mean solar time, will not always happen upon the dates just given. We have stated in Art. 115, that one cause of the variation in the length of the solar days, is the unequal motion of the earth in its orbit. The earth now moves most swiftly in the beginning of the month of January, being then nearest to the sun, and under these circumstances the equation of time becomes nothing at the dates above mentioned. But the time of the year when the earth moves most rapidly is continually changing, and in the course of ages it may occur upon the middle of April, the 1st of January, or any day in the year; and this change will effect a corresponding change in the dates when the mean and true solar time agree.

These points will be more fully explained in a subsequent article, when we have discussed the subject of the earth's orbit, and orbitual motion.

CHAPTER VI.

OF THE ANNUAL MOTION OF THE EARTH.

128. SUN'S APPARENT MOTION IN DECLINATION. If the declination of the sun is measured[1] with an instru-

1. The declination can be found as follows. In the figure, let Q be the place of the observer; HQH[1] the horizon; QNP the direction of the

north pole of the heavens; and EQ that of the celestial equator, and S, S[1] two positions of the sun north and south of the equator. Now, the sum

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Are the epochs when the mean and true solar time agree constant? Why not? What is the subject of Chapter VI? If the declination of the sun is measured from day to day, what changes are observed throughout the year?

ment, as the transit instrument, at noon, day after day throughout the year, it will be found that in the northern hemisphere the declination increases from the vernal equinox, the 21st of March, to the summer solstice, the 22d of June, when it amounts to about twenty-three degrees and a half (23° 27′ 37.4″), the sun appearing to depart continually from the equator, towards the north, and to rise higher and higher in the heavens. After the 22d of June, the declination decreases, the sun appearing gradually to move southward, and to *approach* the equator, which it reaches on the 22d of September, the autumnal equinox, when its declination is nothing; for it will be remembered that declination means distance from the equator. After the 22d of September the declination increases below the equator, to the south, the sun seeming constantly to *recede* from it, sinking lower and lower in the heavens until the 22d of December, the winter solstice, when its declination amounts again, as at the summer solstice, to nearly twenty-three degrees and a half. After the winter solstice it again begins to move northerly towards the equator, where it arrives on the 21st of March, reaching the vernal equinox after *one year* from its last departure.

129. Sun's Apparent Motion in Right Ascension. It is clearly detected by observation that the sun does not approach the celestial equator and recede from it in a line at right angles to the plane of this circle, but that while it is apparently moving to and from the equator, it at the same time seems to advance from *west to east*,

of the three angles, NQH¹, NQE, and EQH, is equal to one hundred and eighty degrees, because HNPH¹ is a semi-circle; but NQH¹ is known, being equal to the latitude of the place Q, and NQE is a right angle, since the equator is ninety degrees from the pole. Subtracting then the value of the first two angles from one hundred and eighty degrees, and we have that of the angle, EQH, the elevation of the equator above the horizon. To find the declination then of the sun, when north of the celestial equator, we subtract EQH from the sun's altitude HQS¹, which gives us EQS¹, which is the declination. When the sun is south of the equator, we subtract the sun's altitude, SQH, from the elevation of the equator, which gives EQS, the declination. Corrections, of course, are made for *refraction* and parallax.

What is detected by observing the sun's apparent motion in the heavens?

in the order of the signs of the Zodiac. The sun's motion in this direction is called its right ascension, and can be found, as in the case of the stars, by means of the transit instrument and astronomical clock. Under the influence, therefore, of these two apparent motions, the sun's visible path in the heavens is a curve, which is found to be a great circle of the celestial sphere, cutting the celestial equator at the equinoctial points, at an angle which measures about twenty-three degrees and a half, (23° 27′ 37.4″.) That it is a great circle, is proved by the fact that the points where it cuts the equator are one hundred and eighty degrees apart; for the sun, in his apparent path, makes the entire circuit of the signs, (three hundred and sixty degrees,) in the space of a year, and the distance between the two equinoxes in time is found to be about six months, equal to one hundred and eighty degrees of angular measurement.

130. SUN'S APPARENT PATH. The sun then apparently moves through the heavens from west to east, describing a vast celestial circle, which cuts the equator in the equinoctial points, one circuit being completed in the course of a year. But, after all, the sun is *stationary*, and this his apparent motion is the result of the actual motion of the earth around the sun. That the earth thus really revolves about the sun, will be rendered evident in a subsequent chapter, when we shall be better prepared to understand and appreciate the proofs. To show that such a motion of the earth perfectly explains the apparent motions of the sun, is our present task.

131. SUN'S APPARENT MOTION IN DECLINATION EXPLAINED. In Fig. 30, where the ellipse delineated represents the orbit of the earth, the latter is exhibited in twelve positions, corresponding to the twelve months. In the several globes, N is the north pole, DCL the equator, S^1 the place of the sun, and CS^1 and all lines from C *parallel* to this the direction of the plane of the ecliptic.

What is meant by the sun's apparent motion in right ascension? What kind of a figure is described by the sun's apparent path? What is the amount of its inclination to the plane of the celestial equator? How is it proved to be a great circle? What is the course of the sun's apparent motion in the heavens? What are we now to show?

It is sufficient for our present purpose to direct our attention to the relations between the sun and earth in four positions only, viz., at the *vernal equinox*, (March,) the *summer solstice*, (June,) the *autumnal equinox*, (September,) and the *winter solstice*, (December.) It is evident from the figure, that at the vernal equinox, since the plane of the equator passes through the sun, that this luminary, viewed from the centre of the earth, will be seen in the opposite quarter of the heavens, on the celestial equator, at its intersection with the ecliptic in Aries. At the summer solstice, the earth assumes such a position in respect to the sun, that the latter is seen from the earth's centre north of the equator, in the line CS^1, which makes an angle with the equator, CD, of about twenty-three and one-half degrees, $(23° 27' 37.4''.)$ The sun, therefore, appears to have advanced north of the equator by this same number of degrees.

When the earth arrives at the autumnal equinox, the plane of the equator again passes through the centre of the sun, which is seen from the earth, as at the vernal equinox, again on the celestial equator at its intersection with the ecliptic; but in the opposite quarter of the heavens, in the sign Libra. At the winter solstice, the sun is seen in the direction of the line CS^1, but the earth has now so changed its position that this line falls south of the equator, making an angle with the latter of about twenty-three and one-half degrees, viz., S^1CL. The sun is now seen nearly twenty-three and one-half degrees south of the equator. We thus perceive that on the supposition that the earth moves while the sun is still, the sun appears on the equator at the time of the two equinoxes, about twenty-three and one-half degrees to the north of it at the summer solstice, and about twenty-three and one-half degrees to the south at the winter solstice. Could we follow the changes of the position of the earth's equator in respect to the ecliptic throughout every day in the year, we should find that these changes account satisfactorily for all the variations

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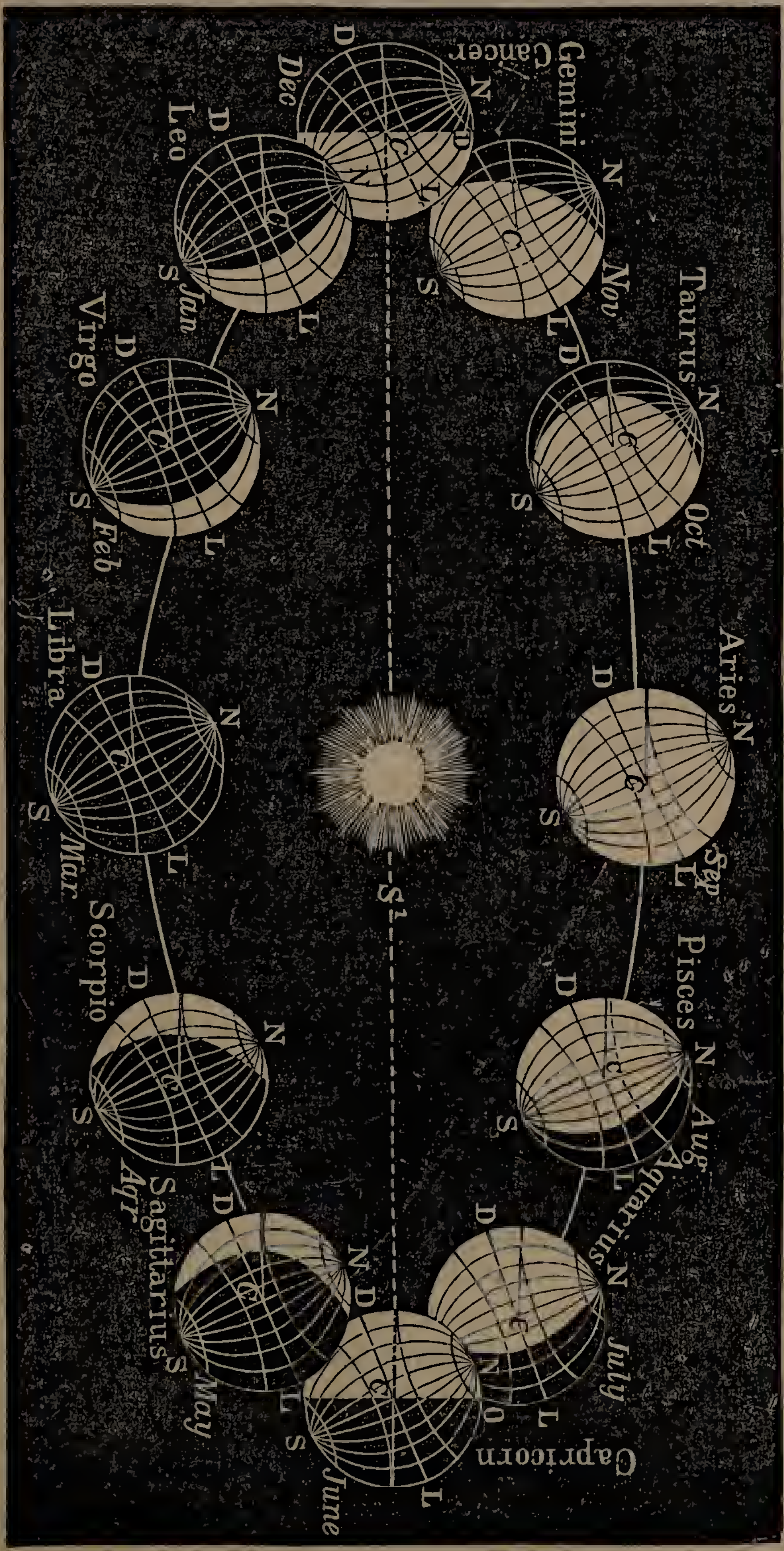
Explain from figure.

FIG. 30



THE SEASONS.

in the sun's daily declination. The apparent motion of the sun in declination is, therefore, the result of the earth's actual motion in her orbit.

132. Sun's Apparent Motion in Right Ascension Explained. If a person passes round a tree in any direction, the tree, though immoveable, appears to move along the distant horizon, following around after him at the distance of half a circumference. In the same manner, the earth being in the sign Libra, the sun appears in the opposite quarter of the heavens, at Aries; and as the earth moves round the sun from Libra to Scorpio, Sagittarius, &c., the sun also appears to follow round in a circle from Aries, through Taurus, Gemini, &c. The real motion of the earth in her orbit then accounts for the apparent motion of the sun in right ascension, from west to east.

133. The circular motion of the earth around the sun thus produces an apparent circular motion of the sun in the heavens, and the apparent motion of the sun to and from the equator is owing to the fact that the plane of the equator is inclined to that of the ecliptic. If they coincided, the sun would always appear moving round in the plane of the equator.

134. Direction of Motion in Space Explained. A difficulty sometimes arises in the mind respecting the direction of motion. The earth rotates on her axis from west to east, and yet the people who live immediately under us, on the opposite side of the globe, appear to move in a contrary direction to what we do. How is this to be explained? We must bear in mind that the *manner in which the constellations that mark the signs of the zodiac succeed each other determines the direction of circular celestial motion.* At night we see these constellations rising above the horizon in the following order, viz., Aries, Taurus, Gemini, &c., and when owing to the rotation of the earth they rise above the horizon of China, they will succeed each other in the same order, and every

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Explain why the real orbitual motion of the earth produces an apparent motion of the sun in right ascension. What is the sun's apparent motion in declination owing to? What is understood when we say that a heavenly body rotates, or revolves, from west to east?

observer upon the earth beholds them rising in this manner. These constellations recurring in this order, the earth is said to revolve from *west to east.* If they succeeded each other in a contrary order, for example Gemini, Taurus, Aries, &c., the earth would revolve from east to west.

We thus see why the sun and the earth, though appearing to move in opposite directions on the great circle of the ecliptic, are yet really moving in the same direction, since they pass through the signs in the same order; the sun apparently passing through them; the earth actually.

CHAPTER VII.

OF THE YEAR.

135. *The length of time employed by the earth in performing an entire circuit from any point in the ecliptic,* as the summer solstice, *to the same point again* constitutes a TROPICAL[1] YEAR, which contains three hundred and sixty-five days, five hours, forty-eight minutes, and forty-seven eight-tenths seconds (365d. 5h. 48m. 47.8sec.) The fractions of a day belonging to a year of this length would be manifestly inconvenient for the purposes of society, and for this reason the civil year is made to consist of three hundred and sixty-five entire days.

136. LENGTH—HOW FOUND. The simplest method of ascertaining the approximate length of the year, and one which was employed by the ancient astronomers, consists in erecting a vertical rod of unchanging length,

1. *Tropical* year so called, from the Greek word *trepö*, *to turn* because the sun reverses its apparent course upon arriving at either *solstice.* In our summer, after advancing apparently as far north as the summer solstice, it then *turns* back to the south, and in winter, after retreating as far south as the winter solstice, it *turns* back to the north.

What is the subject of Chapter VII.? How is the length of a *tropical year* measured? *What is its* length? What is the length of a *civil year?* Why is not the tropical year employed as the civil year? What is the easiest method of ascertaining the length of the year?

on a smooth horizontal plane, upon which plane a meridian line is drawn, and the length of the shadow of the rod marked on the plane every day at noon throughout the year. When the sun rides highest in the heavens on the day of the summer solstice, the shadow will then be the shortest, and the number of days elapsing between two successive returns of the shortest shadow, will be the approximate length of a tropical year.

137. The length of the tropical year was thus at a very early period discovered to be *about* three hundred and sixty-five days. But the difference of nearly six hours which existed between this period and the true length of the year, was soon detected, and its duration was then fixed at three hundred and sixty-five and one-fourth days; the dates of the year were thus made for a time to correspond nearer with the points in the earth's orbit, which they are intended to indicate.

138. A celebrated ancient astronomer, Hipparchus of Alexandria, in Egypt, who flourished one hundred and forty years before the Christian era, discovered however, that this estimation of the length of the year was not correct. Instead of making his observations at the solstice, when the earth moves so nearly parallel to the plane of the equator, that the shadow of the rod shortens for some days, by almost imperceptible degrees, he made them at the equinoxes; when the length of the shadow changes most rapidly, since the path of the earth in its orbit is then most inclined to the equator. By pursuing this method he found that the actual length of the year was less than the computed by a quantity which he estimated at 4m. 48sec. The duration of the year thus corrected was now three hundred and sixty-five days, five hours, fifty-five minutes, and twelve seconds, (365d. 5h. 55m. 12sec.)

From the era of Hipparchus to the present time, various corrections have been made in the length of the year; for within this period the true laws of the universe have been revealed, and astronomers, furnished with instru-

What was the length of the tropical year according to the earliest known observations? What further discovery was soon made? Was the true length of the year now obtained? Who discovered the error? What method of observation did he pursue, and why? What results did he obtain?

ments of surprising accuracy, and aided by new and wondrous mathematical agencies, have attained a precision of calculation almost beyond belief. Yet in the subject before us, the ancient computations have passed through this severe ordeal, almost untouched, for the closest approximation to the true length of the year for 1800, as computed by Bessel is three hundred and sixty-five days, five hours, forty-eight minutes, and forty-seven eight-tenths seconds, (365d. 5h. 48m. 47.8sec.) a result which differs from that of Hipparchus by less than *seven minutes.*

139. THE CALENDAR[1]. In order to avoid fractions in reckoning the length of the year, it has been the custom of all nations who have made any progress in the art of computing time to regard the civil year as consisting of an even number of days —making however, at stated intervals, such corrections, that the real position of the earth in its orbit shall on the whole correspond with the position indicated by any date in the year; so that the seasons shall always occur in the same months, and the solstices and equinoxes return at the same time in their respective months. A moments reflection will show the necessity of such corrections. Four civil years are shorter than four tropical years by nearly one day, (4 × 5h. 48m. 47.8s) so that in every four years about one day would be lost in the reckoning. For if the reckoning commenced at the day of the summer solstice on the 22d of June; four years afterwards on the 22d of June, the earth would not have arrived at the solstice by a day's journey, and the solstice would take place on the 23d. In four years more it would happen on the 24th, and in four more on the 25th, and so on. This mode of reckoning if continued uncorrected would thus in course of time make either solstice, or any other position of the earth in its orbit, occur *successively* on *every day of the civil year.*

1. *Calendar*, i. e., *a register of the year* from the Latin, *calendarium.*

Compare the ancient computations with the modern? What has been the custom of all nations who have possessed a knowledge of the computation of time, in regard to the civil year? Supposing the year to consist of three hundred and sixty-five days only what would happen if no corrections were made?

140. Sothic Period. The ancient Egyptians were aware of this, and purposely suffered their public festivals, though recurring at the same date, to run through the entire natural year. "They do not wish," says Geminus, "the same sacrifices of the gods to be made perpetually at the same time of the year, but that they should go through all seasons, so that the same feast may happen in summer and winter, in spring and autumn." The period in which any festival would pass through an entire civil year of the length of three hundred and sixty-five and one-fourth days is one thousand four hundred and sixty years of the same duration, (1,460,) since one thousand four hundred and sixty years, each consisting of three hundred and sixty-five and one fourth days, are equal to one thousand four hundred and sixty-one years, the duration of each being reckoned at three hundred and sixty-five days. This period of one thousand four hundred and sixty years, at the end of which either the solstice or any other given position of the earth would happen on the same date again, after falling upon every day of all the months of the year, was called by the Egyptians the *Sothic*[1] *period;* because it began on the first day of that year when the *dog star* rose with the sun. The length of the tropical year was computed by the early Egyptians to be three hundred and sixty-five and one-fourth days.

141. Mexicans. The Mexicans regarded the year as consisting of three hundred and sixty-five days, but made a correction of thirteen days for one period of fifty-two years, and twelve for the next, amounting to a correction of *twenty-five days* for every *one hundred and four years.* The accuracy obtained by this method is truly surprising for the excess of the actual over the civil year; viz., five hours forty-eight minutes and

1. *Sothis* in the Egyptian language, means the *dog-star*, which astronomers call Sirius.

What was the custom of the ancient Egyptians? Why did they adopt this custom? In what period of time would any date or festival pass through one entire civil year having a length of three hundred and sixty-five one-fourth days? Explain why. What name was given to this period, and why? What was the length of the tropical year as computed by the early Egyptians? What as computed by the Mexicans? What is said of the accuracy of their correction?

forty-seven eight-tenths seconds, multiplied by one hundred and four, gives as a product *twenty-five days four hours thirty-four minutes* and *fifty-one seconds*, the error of reckoning in a *century* being only about *four and a half hours.*

142. The calendar in use among Christian nations is derived from the Romans. The civil year is here made to consist of three hundred and sixty-five days, the necessary corrections, or intercalations[1] as they are termed, being applied at stated intervals. The first correction in this calendar was made by Julius Cæsar forty-five years before the Christian era. At this time the Roman calendar had fallen into such disorder that ninety days were obliged to be added to the previous year, making it four hundred and fifty-five days long so as to bring the position of the earth in its orbit to correspond with the date of the civil year[2], by this means the error in reckoning which had been accumulating for centuries was destroyed. In order to prevent any future derangement, the rule was adopted of adding one day to every fourth year, by giving February twenty-nine instead of twenty-eight days. This fourth year consisting of three hundred and sixty-six days is called the Bissextile[3] or leap-year.

143. But the Julian correction was too great, because the year was thereby assumed to be three hundred and sixty-five days and six hours long, when in fact it is about eleven minutes shorter (11m. 12.2sec.,) an error which in the course of nine hundred years would amount to very nearly seven days. This small annual error did not at once produce any material derangement in the calendar, but in the year 1414, A. D., it was perceived that the vernal equinox which should always have happened on the 21st of March, if the Julian cor-

1. ***Intercalation***, means ***the insertion of a day in the calendar***, from the Latin ***intercalatio***, the ***putting a day between two others.***

2. This year was called the year of ***confusion.***

3. ***Bissextile***, because in this year the ***sixth*** day before the first of March was reckoned ***twice.*** Latin ***bis*** twice, ***sextus*** sixth. Hence ***Bissextile.***

Whence is the calendar in use among Christian nations derived? What is the length of the civil year, and how are the corrections made? By whom was the first correction of the calendar made? When? Why particularly at this time? How was it made, and what rule adopted? Why is the leap-year called Bissextile? Was the Julian correction exact? Why not? How great an error would arise in nine hundred years?

rection was perfectly exact, was gradually occurring earlier. In the year 1582, the error had amounted to about ten days, and a reform was made by Pope Gregory XIII. It was well known to astronomers that in the year 325 A. D., the equinox fell upon the 21st of March according to the civil reckoning, but in the year 1582, it occurred on the 11th of the same month, the various positions of the earth in its orbit were thus in advance of the dates which should have indicated these positions by *ten days.* The remedy was obvious and consisted in omitting ten nominal days, calling the day next succeeding the 4th of October the 15th, instead of the 5th. This change was made at once in all Catholic countries, but was not adopted in England until the year 1752, by which time the error had amounted to eleven days. The *change of style*, as it is termed, was there effected by an Act of Parliament, decreeing that the day after the 2d of September, old style, should be called the 14th, which was the first day of the new style; and by the same authority the year which before had begun on the 25th of March, was made to begin on the 1st of January. This latter change was accomplished by making the preceding year (1751,) to consist of nine months only, causing it to end at the beginning of the 1st of January instead of the 25th of March. The year 1752 commenced on the 1st of January.

144. By the omission of ten days, Pope Gregory thus reformed the calendar, so that on any day of the year 1583, the earth occupied substantially the same place in its orbit as it did on the same day in the year 325 A.D. But this correspondence was only temporary for the same error of 11m. in the reckoning would work the same mischief in course of time, as it had already done, if let alone; to prevent therefore any future discordance in the calendar, the following rule was adopted under the sanction of the same pontiff.

How much did the error amount in the year 1582? By whom was a reform made? How was the amount of error ascertained? How was it corrected? Where was the change at once adopted? When introduced into England? What was the amount of error then? How was the change of style effected, and what alterations were made in the calendar? How was the second change accomplished? Was the first correction of Pope Gregory all that was necessary to render the calendar perfectly accurate? Why not?

145. Gregorian Rule. *Every year whose number is not exactly divisible by four consists of three hundred and sixty-five days. Every year which is so divisible, but not divisible by one hundred, of three hundred and sixty-six days. Every year whose number is divisible by one hundred but not by four hundred, contains three hundred and sixty-five days; and every year whose number is divisible by four hundred of three hundred and sixty-six days.* Thus, for example, the year 1851, consists of three hundred and sixty-five days, because the number 1851, is not exactly divisible by four, while 1852 consists of three hundred and sixty-six days, because the number 1852 is thus divisible. The years 1700 and 1800, have each three hundred and sixty-five days, because these numbers are exactly divisible by one hundred, but not by four hundred; while the years 1600 and 2000, are leap-years, since four hundred divides these numbers without a remainder. By the adoption of this rule the civil and tropical years are made to correspond so nearly, that an error of only about twenty-two hours, (22h. 39m. 20sec.,) occurs in the space of four thousand years.

CHAPTER VIII.

OF THE PRECESSION OF THE EQUINOXES, CHANGE OF THE POLE STAR, AND NUTATION.

146. Of the Precession of the Equinoxes. The determination of the exact position of the vernal equinox (which is the place in the heavens where the sun apparently crosses the equator in the spring,) is a matter of great importance, since it is the point[1] from whence right ascension is reckoned. Repeated observations taken at

1. The scholar must remember that this point is *imaginary*, it is one of the two points, were two imaginary circles, the equator and ecliptic cut each other.

Give the Gregorian Rule? What is said respecting the correspondence of the civil and tropical year when the rule is employed? What does Chapter VIII. treat of? Why is the determination of the place of the *vernal* equinox a matter of importance? What phenomenon has been detected, and how?

considerable intervals of time have detected a remarkable phenomenon in regard to this point; namely, that it is not stationary in the heavens. For if on any given year the position of the equinox in the heavens is found to be in a line with any fixed star, on the next year it will be seen to the *west* of the star, and in succeeding years the equinoctial point will fall farther and farther to the west of the same luminary. The *annual amount* of this angular motion is only fifty and one-fourth seconds in longitude, ($50\frac{1}{4}''$) and as this quantity is contained twenty-five thousand seven hundred and ninety-one times (25,791,) in one million two hundred and ninety-six thousand seconds, (1,296,000″)[1] or an entire circumference, it takes twenty-five thousand seven hundred and ninety-one years for the equinoctial points to make one complete circuit of the ecliptic.

147. We may form an idea of the way in which this phenomenon occurs by imagining the[2] axis of the celestial equator to revolve about that of the ecliptic from east to west once every 25,791 years, the axes always preserving nearly the same distance from each other. Since the axes are perpendicular to their respective planes, the planes through their entire revolution will preserve their original inclination to each other, and while the pole of the celestial equator revolves around the pole of the ecliptic, the line joining the equinoxes (which is the line of the intersection of the two planes,) will also move round in the plane of the ecliptic from *east to west.* Thus, in Figure 31, if E^1FQ represents the plane of the celestial equator and EFC that of the ecliptic, P^1B the axis of the equator, PB that of the ecliptic, and DF the *line of the equinoxes;* it is evident that if the pole of the equator P^1, revolves in a circle L about the pole of the ecliptic P from east to west two things will occur. *First*, that the equinoctial points D and F will move

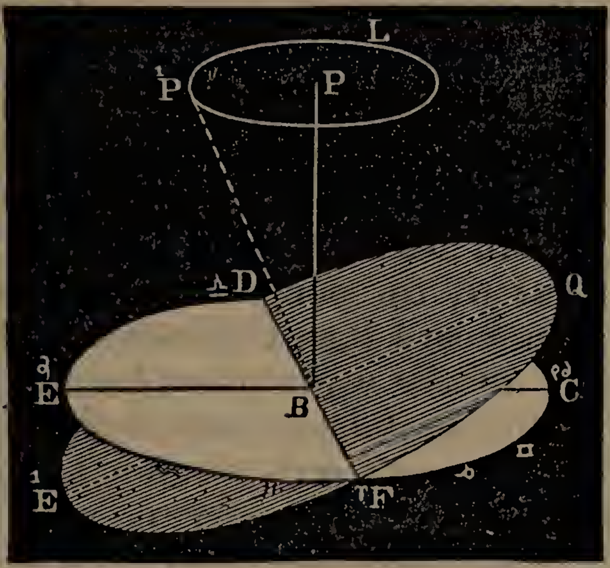
1. $360^\circ \times 60 \times 60 = 1,296,000''$.

2. It will be remembered that the axis of a great circle like the equator is the ***straight line that passes through its centre perpendicular to its plane.***

What is the annual motion of this point in longitude? In how many years would it make the circuit of the ecliptic? In what way can we form an idea of this motion of the equinoctial points? Explain from figure.

round in the *same direction.* *Secondly*, that the planes of the equator and ecliptic will maintain the *same inclination* to each other throughout the *entire revolution* since

FIG. 31.

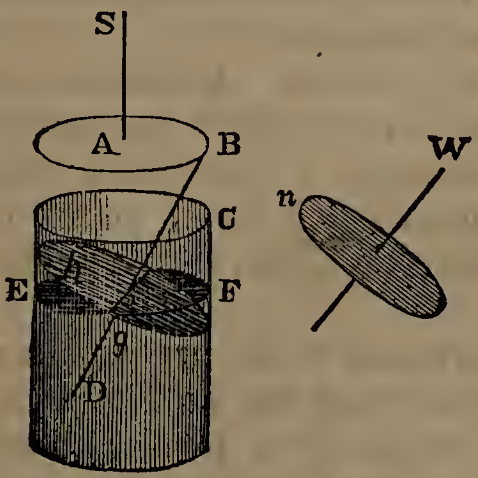


PRECESSION EXPLAINED.

P[1] is always at the same distance from P revolving as it does in a circle about P.

148. The following illustration may tend still further

FIG. 32



PRECESSION EXPLAINED.

to elucidate this subject. Take a tumbler DC, Fig. 32, partly filled with water. The *level surface* of the water,

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Illustrate the subject still further by the aid of Fig. 32

EF, we will call the plane of the ecliptic, and the end A of a thread SA, which hangs over the middle of the tumbler the pole of the ecliptic. Now procure a circle of stiff pasteboard (n), a little smaller than the inside of the tumbler, and through its centre thrust a wire (W,) fixing it perpendicularly to the surface. The plane of the pasteboard represents the plane of the equator, and the wire its axis. Taking now the pasteboard by the wire we place it in the tumbler, causing half the circle to sink below the surface of the water, and half (h,) to rise above, making an angle with the surface of the water EF of about twenty-three and one half degrees. The plane of the pasteboard then represents that of the equator, the surface of the water the plane of the ecliptic, the line where the pasteboard meets the water; viz., *g*, the line of the equinoxes, and around the tumbler at the water-line the signs of the zodiac may be supposed to be arranged, thirty degrees apart. Causing now the upper end of the wire, B, (the pole of the equator) to describe the circumference of a circle around the lower end of the thread, A, (the pole of the ecliptic) from east to west, we shall see that the line where the pasteboard meets the water, that is, the line of the equinoxes, moves also around from east to west; and that the equinoxes which are the extremities of this line, change their position in the same direction.

149. SIDEREAL YEAR. A *sidereal year* is the time taken by the earth to perform *one entire revolution in its orbit*, and is determined by noting the period that elapses during its passage from a fixed star round to the same star again. Hence its name, from the Latin word *sidera*, meaning *stars*.

150. In consequence of the precession of the equinoxes the earth does not perform an entire revolution about the sun, in the course of a tropical year, which it will be remembered is the time that elapses between the departure of the sun from one of the equinoxes to its next return to the same point.

151. Now when the earth leaves the vernal equinox,

What is meant by the term sidereal year? How is it determined? Why so called? Why does it differ in length from the tropical year?

moving in the direction from west to east, the next vernal equinox occurs when the earth *lacks fifty and one-fourth seconds*[1] of angular motion of completing its revolution around the sun. The time the earth takes to pass through an arc of fifty and one-fourth seconds, is twenty minutes, and twenty-two nine-tenths seconds of mean solar time, which must be added to the length of the tropical year to make a *sidereal* year. The length of the tropical year is 365d. 5h. 48m. 47.8sec., adding to this 20m. 22.9sec. we have, 365d. 6h. 9m. 10.7sec. for the length of the sidereal year.

153. CHANGE OF THE POLE STAR. Another result of the precession of the equinoxes is the curious fact that the axis of the earth is *not always directed* to the *same points in the heavens*, and since the axis of the earth prolonged to meet the starry vault, becomes the axis of the heavens, *the poles of the celestial sphere are not stationary in the sky.* Conceiving the pole of the equator to revolve slowly around the pole of the ecliptic in the manner already explained, it is evident that while the former approaches some stars it must recede from others. That star which is *nearest* to the pole of the equator is always termed the *pole star.*

154. The present pole star (which is in the constellation[2] of the Lesser Bear, at the end of the tail,) though now only *one degree and a half* from the pole, was at the time of the construction of the earliest star maps, twelve degrees distant from it. The *north* pole of the heavens will continue to approach this star until it is within *half a degree*, when it will begin to recede, and in the course of twelve thousand years, the brightest star in the constellation of the Lyre will become the pole star. For although this luminary is now more than fifty-one degrees (51° 20′ 49″) distant from the pole, it will then

1. More nearly 50.24.″

2. *Constellation*, a cluster of fixed stars. The stars have all been grouped into constellations by astronomers.

What is the amount of this difference? What is the length of the sidereal year? Are the poles of the heaven stationary? Why not? What is meant by the term *pole star?* State what is said respecting the present pole star? What changes will occur in regard to the pole star in the course of twelve thousand years? Is the pole star always the same orb?

be within the distance of *five degrees*. The pole star is not therefore forever and unchangeably the same luminary.

155. EFFECT OF PRECESSION ON THE RIGHT ASCENSION AND LONGITUDE OF THE STARS. Since the *vernal equinox* is the point from whence the position of the stars is determined both in respect to *longitude* and *right ascension*, the backward motion of the equinoxes necessarily produces a slow change in the amount of these measurements though the relative positions of the stars remain unaltered. Just as the several distances of all the trees in a grove, *from a boat* slowly floating down a neighboring river, are continually changing, since the point from whence these distances are reckoned is constantly moving, while the distances of the trees from one another remain fixed.

156. ON THEIR DECLINATION AND LATITUDE. On account of the precession the *declination* also of the stars does *not remain constant;* for since the axis of the equator, as it moves around that of the ecliptic, is always at right angles to the plane of the equator, this plane has necessarily a corresponding motion among the stars. From century to century the distances of the fixed stars from the celestial equator must therefore vary, and these distances are their declinations. The *latitude* of the stars *experiences no change* from this cause, since the precession produce no variation in the position of the ecliptic from which the latitudes are reckoned.

157. TERRESTRIAL LATITUDE CONSTANT. Terrestrial latitudes are unaffected by the precession of the equinoxes, which shows that the change in the position of the earth's axis in space, is not a mere shifting of the line about which the earth rotates; for if this was so the geographical situation of places in respect to the poles, or what is in effect the same *their latitudes*, would also change, which is not the case. The earth therefore *rotates about an axis invariably the same*, and in the motion of this axis around that of the ecliptic, "the entire body

State what is said respecting the effect of precession on the *right ascension* and *longitude* of the stars? What on their *declination* and *latitude?* Does the precession affect terrestrial latitudes? What does this fact show? What is said respecting the earth's axis?

of the globe participates," says Herschel, "and goes along with it as if this imaginary line were really a bar of iron driven through it. This is not only proved by the unchangeability of the latitudes, but also by the fact that the sea maintains invariably its own level which would not be the case if the axis of rotation changed."

158. RELATIVE POSITIONS OF THE SIGNS AND CONSTELLATIONS OF THE ZODIAC VARIABLE. On account of the precession of the equinoxes the *signs* of the Zodiac do not now correspond with their respective *constellations*, but have retrograded through the heavens the space of one sign or thirty degrees.

159. When the vernal equinox occurs the sun is at the first point in the *sign Aries*, in the Zodiac, but at this time he is seen from the earth, not in the *constellation Aries*, but in that of Pisces thirty degrees distant from the first point in the sign. The same change has taken place in all the signs, each has *moved backwards thirty degrees*, so that the *sign Aries* is now in the *constellation of Pisces*, the *sign Taurus* in the *constellation Aries* and so on throughout the entire Zodiac.

160. When the first catalogues of stars were constructed the signs doubtless corresponded with their constellations in position, and we can therefore calculate the era when the earliest star charts were made. Thus the *rate of precession for one year*, (50.24″) is to *one year* as *thirty degrees* (108000″) is to 2149.7 years. The Zodiac was therefore constructed about two thousand years ago.

It is important to discriminate clearly between the *signs* of the Zodiac and the *constellations*. *The constellations* of the Zodiac are *groups of fixed stars in the plane of the ecliptic unchanged* in position by the precession. The *signs* of the Zodiac are *twelve equal divisions* of the great circle of the ecliptic, bearing the same names as the constellations. They are reckoned from the vernal equinox beginning with Aries, *forward* through Taurus, Gemini, and so on. The *backward* motion of the *vernal equinox*

What does Herschel observe? What additional proof of the constancy of the earth's axis is adduced? State what is said respecting the want of correspondence between the *signs* and *constellations* of the Zodiac? When did the signs and constellations of the Zodiac correspond in position? Prove it. Explain the terms *constellations and signs of the Zodiac?* How are the latter reckoned *forward?*

carries back all the signs at the same rate through the fixed series of *constellations.* In about twenty-four thousand years from the present time, the signs will again correspond with their constellations.

CAUSE OF THE PRECESSION.

161. We have seen in our investigation of the figure of the earth that there exists an excess of matter around the equator; the equatorial diameter being twenty-six miles longer than the polar. A ring of solid matter thirteen miles in thickness, therefore, surrounds the earth at the equator above what is necessary for forming a perfect globe, having an equatorial diameter equal in length to the polar diameter. Now it is the action of the sun, moon, and planets upon *this ring* which produces such a displacement in the position of the equator, in regard to the ecliptic as gives rise to the precession of the equinoxes.

162. INFLUENCE OF THE SUN. The action of the sun is as follows. This vast globe being in the plane of the ecliptic, to which the plane of the ring is inclined about twenty-three and one half degrees,[1] tends by its attractive force to draw down the ring to the plane of the ecliptic, while at the same time the earth, and of course the ring, is revolving on its axis from west to east.

163. The effective force of the sun acts at *right angles* to the *plane of the equator* and the *force of the rotation in the* plane of the equator from west to east. The rotating ring of matter is therefore acted upon at the *same time* by *two forces*, one of which causes it to rotate from *west to east*, and the other to *draw it down* to the *plane of the ecliptic.* By their joint action, the ring really moves as if drawn by *one force* acting *obliquely to its plane*, and is as it were twisted round from east to west, intersecting

1. The plane of the ring is that of the equator, and its inclination to the plane of the ecliptic will be the same; viz., 23° 27′ 36,5″, or about 23½.

How long will it be before the signs and constellations correspond in position? What is the cause of the precession of the equinoxes? Explain the action of the sun? What two forces combine to produce the precession? What is the effect of their joint action?

the ecliptic at points *westward* of those were it cut it *before.*

164. The ring is moved in the same manner as a boat which sails directly across a river from west to east, while at the same time it is slowly drawn down the stream by the current. By the union of both these forces it descends the river as if influenced by a single force acting obliquely to the keel. Every one will of course understand that the ring in its motions carries the earth along with it.

165. INFLUENCE OF THE MOON AND PLANETS. The moon's influence in causing the precession of the equinoxes, is greater than that of the sun, on account of its being nearer to the earth, being as seven to three; and their united effect produces a displacement of the equinoxes from east to west. The attraction of the planets is, however, exerted in an *opposite direction*, causing a very small advance of the equinoxes from west to east. The actual precession is the *first motion* diminished by the latter. The result obtained is that already stated, namely, 50.24″.

NUTATION.

166. We have stated that the precession of the equinoxes is caused by the attraction of the sun, moon, and planets, upon the excess of matter at the earth's equator, and that in consequence of this action the pole of the equator describes the circumference of a circle around the pole of the ecliptic in about twenty-six thousand years. If this action of the sun and moon was *always the same*, the path of the pole of the equator *would be a circle;* but this is not the case, for the force of the sun *varies*—its influence being *greatest* upon the equatorial ring, when it is *farthest from the earth's equator*, namely, at the *solstices*, and *least*, vanish-

1. *Nutation*, from the Latin word *nutatio*, a nodding, a moving from one side to the other.

Give the illustration. State what is said respecting the influence of the moon and planets. Explain nutation. Solar.

ing to nothing, when it is *at the equator*, namely, at the time of the *equinoxes.*

168. A similar inequality likewise exists in the moon's action, arising from a like cause. There is, however, this difference. The *variations* in the *solar* force all occur in the space of *one year*, those of the *lunar* within the period of about *eighteen and a half years.*

169. This variation of force produces the *nutation*, and the pole of the equator, if free from any other influence, would, in virtue of this, describe among the stars a *small ellipse* in a period comprising about eighteen and a half years; the longer axis of the ellipse being about 18″.5, and the shorter, 13″.7. The *centre* of the ellipse lies in the *circumference of the circle* which would be described by the pole of the equator round the pole of the ecliptic, if the force producing the precession *never varied.*

170. This subject is illustrated in Fig. 33, where the

FIG. 33.

NUTATION.

circumference, B, of the large circle, represents the path that the pole of the equator, P^1 would describe around the pole of the ecliptic, P, if *precession alone* existed; and A, is the small ellipse which P^1 would describe if *nutation*

Lunar. Within what period of time do the solar variations occur? Within what the lunar? What kind of figure does the pole of the equator describe in consequence of nutation? What is the extent of this ellipse? Where does its centre lie? Illustrate this subject by figures 33 and 34.

occurred *without* precession. Now, since these motions *co-exist*, it is evident that neither a perfect circle nor a complete ellipse will be described by the pole, P[1]; but at one time it will be outside the circumference, B, and at another within, revolving about P all the while. It will, therefore, actually describe a circular waving path, like that exhibited in Fig. 34, where P is the pole of the ecliptic, and the pole of the equator advances towards P and recedes from it, as it follows the path, AA^1BB^1, and so on.

FIG. 34.

NUTATION.

171. The influence of the moon in producing nutation is to that of the sun, as five to seven.

172. OBLIQUITY OF THE ECLIPTIC AFFECTED BY NUTATION. It is evident from an inspection of the above figure that the pole of the *equator* approaches to and recedes from the pole of the ecliptic at determinate intervals of time. The inclination of the plane of the equator to that of the ecliptic must, therefore, fluctuate in the same manner, since the axes of the equator and ecliptic are always at right angles to their respective planes. A variation, termed *secular*, also exists, extending through centuries, as is shown by the following table:

What is the ratio of the moon's influence to the sun's in producing nutation? Is the obliquity of the ecliptic effected by nutation? Why? Do recorded observations also show a *secular* change in the obliquity? Prove this from the table given

Date.	Observers.	Obliquity.
B. C.		
1100	Tcheou-kong, (Chinese,)	23° 54′ 02″
324	Pytheas, of Marseilles,	23° 49′ 20″
140	Hipparchus, ...	23° 51′ 15″
A. D.		
830	Almamun, ...	23° 33′ 52″
879	Albategnius, ...	23° 35′ 00″
1690	Flamsteed, ...	23° 28′ 56″
1825	Bessel, ...	23° 27′ 43,4″

173. The change in the situation of the pole of the equator arising from nutation will likewise cause a slight periodical variation in the right ascensions, declinations, and longitudes of the fixed stars.

CHAPTER IX.

OF THE EARTH'S ORBIT.

174. The path described by the earth in its revolution about the sun is an ellipse; this is proved by observation in two ways. First, by the *changes in the apparent diameter of the sun*. Secondly, by *variations in its apparent velocity*. The following illustration will enable us to understand why these changes lead to a knowledge of the true form of the earth's orbit.

175. Suppose that above the centre of a large *circular* field, an immense gilt globe was fixed in an elevated position, and that a person drove around the field *always* preserving the *same pace*, and keeping at the *same distance* from the globe. Under these circumstances (if he were unconscious of his own motion) the globe would *appear* to move around him with the *same unvarying motion*, and to be always of the *same size*. But if the field was *elliptical* in shape, and the globe above one of the foci, and the experimenter drove *most rapidly* when

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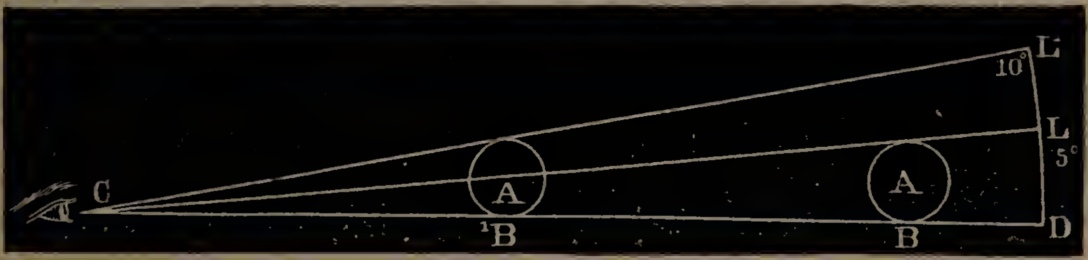
What other variations does nutation cause? What is the subject of Chapter IX? What is the figure of the path described by the earth around the sun? In what two ways is this proved? Give the illustration.

nearest the globe, and *slowest* when *most remote* from it, he would, (being unconscious of his own motion, as before,) behold the globe *changing its apparent size* and *rate of motion* as it performed its seeming circuit around him; possessing the *greatest apparent size* and *swiftest velocity* when *nearest*, and appearing the *smallest* and *moving the slowest* when *most distant*.

176. It is in this manner that we view the solar orb. Our globe is the car on which we ride, and we sweep through space around the sun at differing distances from it, and with changing speed; but all unconscious of our own motion, the sun *seems to move around us*, varying its velocity and apparent size. These changes in respect to the sun show that it is *not in the centre of the figure* that the earth describes around it. The true figure of the orbit is found in the following way.

177. Apparent Diameter. If the *apparent diameter* of the sun is taken at stated intervals as at noon throughout the year, and his *apparent daily angular motion in the ecliptic* is likewise observed, we have the means of solving this problem. It is a law in optics, that the apparent magnitude of a body *is inversely proportioned to its distance*;[1] that is if at a certain distance it appears of a certain size, when *ten times nearer* it will appear *ten times larger*, and if *five times farther* off *five times smaller*, and so on.

1. This law is easily understood by the aid of the annexed cut, where the *same* body, represented by the circle A, is placed at different distances



from the eye at C. At the distance CB[1] the body A is seen under the angle DCL[1] which is 10°. *Ten degrees* is at this distance its *apparent diameter*. At the distance CB which is *twice* CB[1] the apparent diameter of A is LCD, *the half* of DCL[1] or an angle of *five degrees*. Thus the law is proved.

Apply it to the motions of the earth in reference to the sun? What do the changes mentioned show in respect to the position of the sun?

178. Bearing this law in mind, and having all the above observations, we take upon a card a point E, Fig. 35, which we call the earth and another S, the sun, and

FIG. 35

EARTH'S ORBIT.

draw a line SE one inch in length for instance, representing the distance of the sun from the earth on the day when the sun appears the largest. We now draw for the next day a line ES^1 making an angle with ES equal to the observed angular motion of the sun, since it was at S the day before; and we determine the length of the line ES^1 by making it as much *longer* than SE, as the *apparent diameter* of the sun when at S^1 is *less* than when at S. For the next day we proceed in the same manner, and so on for the entire year, fixing the *distances* of the lines ES, $ES,^1$ $ES,^2$ &c., *from* each other by means of the *apparent daily motion* of the sun, and determining the *length* of these *lines* by the *variations* in its *apparent diameter*. Then joining the ends of these lines we have a figure that represents the orbit of the earth.

179. The figure thus approximately formed is similar to an ellipse, and which by rigorous and refined calculations is proved to be an exact ellipse. We must recol-

State the manner in which the true orbit is approximately found? What has been proved by rigorous mathematical calculations? What must we recollect?

lect however, that since it is the *sun* which is *stationary*, and the *earth* that *moves*, the true place of the sun in the figure is at E, one of the foci of the ellipse, while the earth moves round in the curve occupying the positions S, S^1, S^2, S^3, &c.

180. The apparent diameter of the sun which is its angular breadth, can be measured by various instruments, but one called a heliometer,[1] is constructed particularly for this purpose. When the earth is farthest from the sun, the apparent magnitude of the latter is 31′ 31″ and when nearest 32′ 35″.

181. That point in the orbit of the earth, or in that of any planet or comet, which is *nearest* to the sun is called its *perihelion*,[2] and that which is most *remote* its *aphelion*,[3] the *former* term signifying *about the sun* and the *latter* meaning *from the sun.*

In the case of the earth its perihelion is also called the *perigee*,[4] and its aphelion the *apogee.*[5] These terms are used in reference to the *apparent approach* and *recession* of the sun from the earth.

The perihelion and aphelion, have also the name of *apsides*,[6] and the line which joins them is termed the *line of the apsides.*

182. ANOMALISTIC YEAR. The places of the perihelion and aphelion are *not fixed* as regards absolute space but have a gradual *motion* from *west* to *east.*

183. If we were to note this year the exact time when the sun had the *greatest apparent diameter*, at which moment the earth of course would be at its perihelion, and determine at this instant the position of the earth in reference to the fixed stars, on making the same obser-

1. ***Heliometer***, from the Greek ***helios*** the sun, and ***metron*** a measure i. e., a sun-measurer.
2. ***Perihelion***, from the Greek ***peri***, about, and ***helios*** the sun.
3. ***Aphelion***, from the Greek ***apo***, from, and ***helios*** the sun.
4. ***Perigee***, from the Greek ***peri***, about, and ***gë***, the earth.
5. ***Apogee***, from the Greek ***apo***, from, and ***gë***, the earth.
6. ***Apsides***, from the Greek ***apsis***, meaning a binding together. Any curved form.

How is the ***apparent diameter*** of the sun measured? What is the magnitude of the apparent diameter when the earth is farthest from the sun? What when nearest? What is meant by the term perihelion, aphelion, perigee, apogee, apsides, and the line of the apsides? Are the places of the perihelion and aphelion fixed in space?

vation the next year, we should find that the perihelion occurred nearly 12″ of space (11.29″) to the *east* of its *position* the *year before.*

184. Year after year this motion continues in the same direction. The earth therefore, in moving from its perihelion to its perihelion next again, a *period* which is termed the *anomalistic*[1] *year*, performs one *entire revolution* and about 12″ over. This small space is converted into time, as follows: 360° : 365 days 6h. 9m. 10.7sec., (the length of a sidereal *year*) : : 11.29″ : 4m. 34.9sec. The length of the *anomalistic year* is therefore, 365d. 6h. 13m. 45.6sec.

185. This motion of the perihelion from west to east, may be conceived to take place as if the line of the apsides had a slow motion from west to east; or as if the earth's orbit, imagined to be a solid elliptical ring moved about the sun as a *pivot;* the line of the apsides, making an entire revolution in *about* 115,000 years.

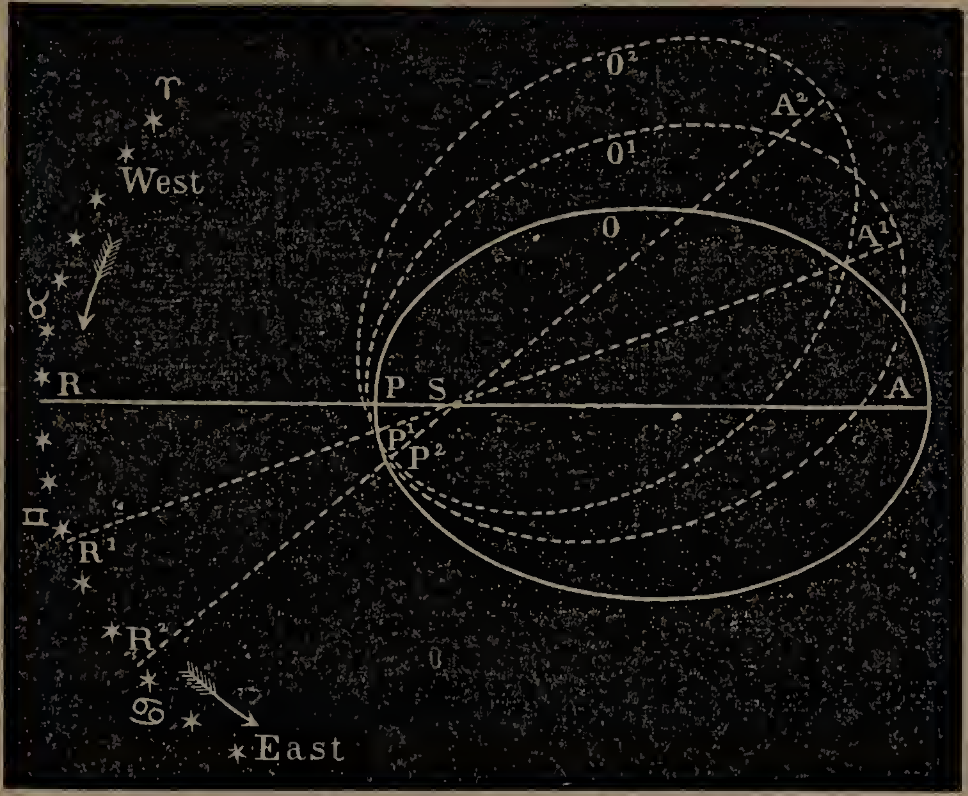
186. This subject is illustrated in Fig. 36, where Aries, Taurus, &c., represent a part of the ecliptic, S the sun, and AOP, $A^1O^1P^1$ and $A^2O^2P^2$, the position of the earth's orbit at different times. The aphelion in the three positions is at A, A^1, A^2, the perihelion at P, P^1, P^2, and the line of the apsides takes the directions APR, $A^1P^1R^1$, $A^2P^2R^2$; the places of the perihelion P as referred to the *heavens* occupying successively the points R, R^1, R^2, as the line of the apsides moves from *west to east.* Thus though the earth's orbit preserves the same form and the earth maintains the same distances from the sun at every revolution, yet the orbit itself may and does vary its position in space continually.

187. Apparent Angular Motion. The *apparent angular motion* of the *sun* in the ecliptic, is obtained from observations on its *right ascension* and *declination;* and these measurements are made by means of the transit

1. ***Anomalistic***, from ***anomaly***, an ***irregularity***.

What is the amount of the *annual* change in the position of the perihelion? In what direction does it move? Is this motion constant? What is meant by the term *anomalistic* year? What is its length? How may this motion of the perihelion be conceived to take place? In how long a time does it take for the line of the apsides to make one revolution? Illustrate from figure. How is the apparent angular motion of the sun measured?

FIG. 36



ANOMALISTIC YEAR.

instrument or *mural circle*,[1] and the astronomical clock.[2] The daily apparent velocity of the sun at *apogee*, is nearly 57′ 12″ (57′ 11.48″,) and at *perigee* 1° 01′, which is the same as saying that the earth's *actual daily motion* at her *aphelion* is 57′ 12″, and at her *perihelion* 1° 01′.

188. VARIATION IN THE EARTH'S ORBITUAL VELOCITY. It might be supposed that these variations in the sun's apparent daily velocity are *entirely* owing to the periodical changes in its distance from the earth; since if the latter were always to move through its *orbit* with the *same speed*, its *angular* velocity would be *inversely pro-*

1. The mural circle, is an instrument especially employed for measuring arcs on the meridian. It is a graduated circle *much larger* than that usually connected with the transit instrument, and consequently much smaller arcs can be measured upon it. It is termed a *mural* circle, because when in its place it is firmly connected with a *wall*. *Murus*, in Latin, signifies a *wall*.

2. It will be recollected that the *clock* is only used in taking *right ascensions*.

What is the daily apparent velocity of the apogee? What at perigee? What is this the same as saying? What might at first be supposed to be the cause of the variations in the earth's orbitual velocity?

portioned to its *distance* from the *sun*.[1] But these changes in distance *will not account* for the changes in angular velocity to the *full extent* of the latter; for the observations of astronomers show, that the angular velocities of the earth at any two points of its orbit are not to each other *inversely as the distances*, but as the *squares*[2] *of* the *distances* at these points, a fact which proves that the earth *actually moves faster* according as it is *nearer to the sun*.

189. FORM OF THE EARTH'S ORBIT ASCERTAINED BY ANGULAR VELOCITIES. We have just seen that the angular velocities at any two points of the earth's orbit are inversely as the squares of the distances at these points. The *square roots*[3] of the *angular velocities* will, therefore, be *inversely* proportioned to the *distances*.[4] Observing therefore, from day to day, the sun's apparent angular velocity, we can thus obtain the relative distances of the sun from the earth throughout an entire year; and having these, we can proceed to map down the figure of the earth's orbit in the manner already explained in Art. 178.

190. PRODUCT OF THE SQUARE OF THE DISTANCE INTO THE ANGULAR VELOCITY.—CONSTANT. From the relation that exists between the angular velocities of the earth in its orbit and its distances from the sun, it results, that if the *angular velocity* of the earth for any

1. This fact is easily proved. If from a common centre we describe ***two circles***, and the radius of the larger circle is ***twice*** as ***long*** as that of the smaller, then the circumference of the larger circle will also be twice as long as that of the smaller. Now if two bodies start together the ***first*** on the ***smaller*** circumference and the ***second*** on the ***larger*** with the ***same velocity;*** by the time the ***first*** has made ***one revolution*** or 360°, the second has only made half a revolution or 180°. In other words that body which is ***twice*** as far from the centre as the other, has only ***half*** the ***angular motion*** of the latter.

2. The square of a number is the product arising from multiplying the number ***once into*** itself, thus 4 is the ***square*** of 2; because 2×2 equals 4.

3. The square root of a number is ***such*** a number as multiplied into itself, will produce the first number. Thus the square root of 4 is 2, because 2×2 gives 4.

4. If four quantities are in proportion, their square roots will also be in proportion; thus, if 4 : 16 : : 9 : 36, then 2 : 4 : : 3 : 6.

What do the observations of astronomers show? What is proved by this fact? What can be determined by the angular velocities? What results from the relation that exists between the angular velocities and distances.

given period is *multiplied* into the *square* of its *distance from the sun* at that time the *product will always be the same.*

191. For when *one quantity increases* at exactly the *same rate* as another *decreases*, they are said to vary inversely, and their product is *always the same.* Thus if a locomotive passes over a given space with a certain speed and in a certain time; if the *speed* is *doubled* and the *time halved*, or the *speed halved* and the *time doubled* the *same* space will still be passed over; and this will constantly be true if *one* of these two quantities is always *increased* in just the *same ratio*[1] as the *other* is *diminished.*

192. It follows from this fact, since the *angular velocity* of the earth *varies inversely* as the *square* of its *distance* from the sun, that the *product* of the *angular velocity* of the earth for any given period *into the square of its distance* at that time is *invariably the same.* Thus, for instance, the *angular velocity* for the 20th day of June, *multiplied* by the *square of the distance* that *the earth* is then from the sun, is *equal* to the *product* of the *square of the distance* and *angular velocity* for the 20th of December, and so for any other day in the year.

From the preceding relations another result is also obtained, which is expressed in astronomical terms, by saying that the *radius-vector*[2] *of the earth describes areas directly proportional to the times.* This expression signifies, that if the centres of the earth and sun were connected by a line, and this line moved around the sun as on a pivot carrying forward the earth in its orbit; that then the *spaces swept over by the line*, would exactly *correspond in extent* with the *times* that the line was in motion; for instance, that the space passed over by the radius-vector in *two days* is *double* that swept over in *one*, one-*half* of that described in *four*, &c. To illustrate. In Fig. 35, where SE is a radius-vector, if the earth is sup-

1. That is, if *one* of these quantities is *multiplied* by any number the *other* is *divided* by the same number.

2. Derived from the Latin word *vector*, signifying a *carrier*.

What is true in respect to the *product* of two quantities that are inversely proportional What follows from this fact? What other result is stated? What does this expression signify? Give instances? Illustrate from figure.

posed to describe the arcs SS^1 and S^1S^2, in the *same time*, bringing the radius-vector successively into the positions S^1E and S^2E, then the areas SES^1 and S^1ES^2, are *equal.*

KEPLER'S LAWS.

193. The principle just stated, is one of the *laws* of Kepler. This distinguished astronomer, who flourished about 250 years ago, discovered THREE great laws of planetary motion, which from their importance are termed the laws of Kepler. They are enunciated as follows:

FIRST LAW. *The planets move in ellipses around the sun, which occupies a focus common to all these ellipses.*

SECOND LAW. *The radius-vector describes areas proportioned to the times.*

THIRD LAW. *The squares of the periodic*[1] *times of the planets are proportional to the cubes*[2] *of their average distances from the sun.*

EXTENT OF THE EARTH'S ORBIT.

194. We have discovered the *form* of the earth's orbit by ascertaining its relative distances from the sun during its annual circuit, but the *actual extent* of this orbit can only be known when we have the *real distance* of the earth from the sun in some *known measure* as miles. In what manner it is computed we will now explain.

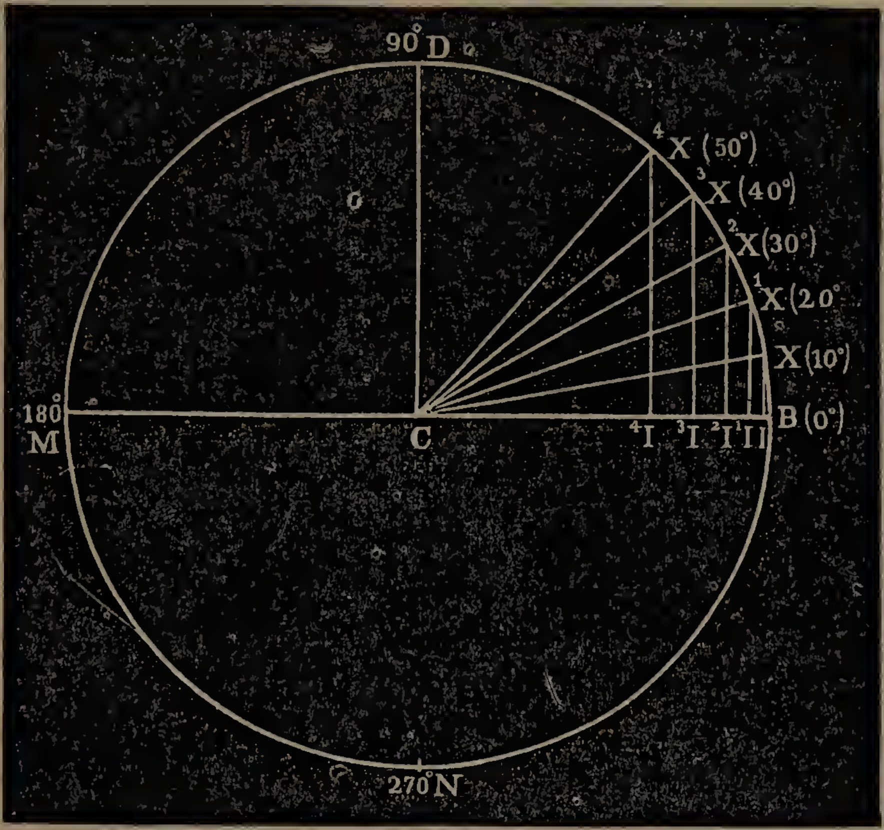
195. HOW ASCERTAINED. In order to solve problems like these mathematicians have taken the circumference of a circle as BDMN, Fig. 37, and divided it into arcs of *degrees*, *minutes* and *seconds*, beginning to reckon from B. Lines, like XI, X^1I^1, X^2I^2, X^3I^3, &c., are then drawn, or supposed to be drawn from *one extremity of*

1. ***Periodic time*** is the time occupied by a planet in performing ***one revolution about the sun.*** Thus, one year is the periodic time of the earth.

2. ***A cube*** is the quantity resulting from multiplying a quantity into itself twice; thus 8 is the ***cube*** of 2 because 2×2×2 equals 8.

State the *laws* of Kepler? Have we as yet ascertained the *dimensions* of the earth's orbit? What have we discovered? How can the actual extent of the earth's orbit be obtained?

FIG. 37



CIRCLE WITH TRIANGLES.

each arc perpendicular to the diameter MB, *passing through the other extremity*, making with portions of this diameter and the several radii, CX, CX^1, CX^2, &c., a series of *right angled triangles;* viz., CXI, CX^1I^1, CX^2I^2, &c. Giving next some particular value to the radius of the circle, as a foot for instance, they have calculated in parts of *the radius* the *value* of the *heights*, (XI, X^1I^1, &c.,) and the *bases* (CI, CI^1, &c.,) in as *many right angled triangles* as there are *seconds* in *one quarter of the circumference from B to D.* These *results* set down in order with others of the like nature constitute what are termed *trigonometrical tables.* Bearing in mind these facts we will proceed to the second part of the explanation.

196. In Fig. 38, S represents the centre of the sun, E that of the earth, SL is a line supposed to be drawn from the centre of the sun, touching the earth at L, and necessarily at right angles to the radius of the earth LE; and ES is an imaginary line, connecting the centres of the

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Explain the method taken by mathematicians to solve problems like these?

FIGS. 38 & 39

SUN'S DISTANCE MEASURED.

earth and sun. SLE, therefore, constitutes a right angled triangle, and the angle LSE is the average horizontal parallax of the sun, equal to 8″ 6.

197. Now we *know* the length of the line LE, which is half the earth's diameter, to be 3,956 miles, and as we have the value of two angles in the right angled triangle SLE, we can find that of the third, since the *sum* of the angles of any *rectilinear triangle* is always *equal to 180 degrees*, Art. 13. These things being known we can obtain the *real distance* of the sun by a *simple proportion*. Looking into the trigonometrical tables we select a right angled triangle whose angles are respectively equal to those in SLE, let CBD, Fig. 39, be that triangle, the lengths of whose *base*, *hypothenuse*[1], and *height* have *all been calculated*, and are set down in the tables. But as SEL and CBD are similar triangles, the sides about the equal angles are proportional (Art. 14,) i. e. the *hypothenuse* of *one* is to the *hypothenuse* of the *other*, as the *height* of the *one* is to the *height* of the *other*; and so of the *bases*. To obtain therefore, the distance of the sun, we should make the following proportion; namely, BD : CB : : LE : SE.

198. Now we find from the tables that if CB is *one mile in length*, then the value of BD is equal to *four thousand one hundred and sixty-nine hundred millionths*

1. *Hypothenuse*—the hypothenuse of a right angled triangle, is the side opposite the right angle.

Calculate the distance of the sun from the earth?

of a mile(.00004169.) Substituting the values of the first three terms of the above proportion, it would stand thus:

$$\begin{array}{ccccc} (BD) & & (CB) & & (LE) \\ (.00004169) & : & 1 & :: & 3956 : SE \end{array}$$

By the rule of three, SE will therefore, equal the product of the second and third terms, divided by the first, to wit:

$$\frac{(3956 \times 1)}{.00004169}$$

which gives 94,900,000 miles, for the value of SE, *the distance of the sun.* In round numbers therefore, the average distance of the earth from the sun is 95,000,000 of miles; at the *perigee*, it is 93,000,000, and at the *apogee*, 96,000,000.

The extent of the orbit of the earth is estimated at about 600,000,000 miles,[1] and through this immense space it sweeps in the course of a year, at the rate of nineteen miles per second.

CHAPTER X.

OF THE SEASONS.

199. THE SEASONS. The changes of the seasons, depend upon *three causes. First*, the fact that the sun illumines but one half of the earth at a time; *Secondly*, that the axis on which the earth revolves is inclined to the plane of the ecliptic; *Thirdly*, that its position at any one point in the earth's orbit is invariably parallel to its position at every other point.

1. Though the earth's orbit is an ***ellipse*** the eccentricity is very small, and we may regard it as almost a perfect circle. Considering the orbit as ***a circle*** we ascertain its ***extent*** by the rule for finding the circumference of a circle from knowing its diameter. Multiplying therefore, 190,000,000 miles by 3.14159, we obtain in round numbers 600,000,000 miles, for the length of the earth's orbit.

What in round numbers is the average distance? What the least and what the greatest? What is the extent of the earth's orbit? What is its orbitual velocity per second? What is subject of Chapter X.? Upon how many causes does the changes of the seasons depend? Name them?

The axis[1] of rotation is inclined to the plane of the ecliptic about sixty-six and a half degrees, and *constantly points* to the *same place*[2] in the celestial sphere, during an entire revolution of the earth in its orbit. For although in the interval of six months it shifts its position in space the extent of the diameter of the earth's orbit; viz., one hundred and ninety millions of miles, yet this is so small a *distance* compared with that of the fixed stars, that at one of these stars our globe, if it was possible to see it, would *not appear to move;* the vast area included in its orbit, dwindling down to a mere point. If, therefore, the *axis* of the earth *points* to any place or star in the celestial sphere, it will *continue* to *point* to it in every position that the earth assumes in her revolution about the sun.

200. By the aid of Fig.[3] 40, we shall be enabled to perceive how the variety of the seasons is produced by the causes just mentioned. In this cut, S^1 represents the sun, the *twelve globes* indicate the several *positions* of the earth in its orbit, in the successive *months of the year* with the *corresponding signs*, and the dotted line CS^1C gives the *direction* of the *plane* of the *ecliptic.* In the several globes C is the centre of the earth, DCL is an equatorial diameter and shows the *direction* of the *plane* of the *equator;* the diameter at right angles to this; viz., NCS is the *axis* of the *earth* and its *extremities* the *north* and *south* poles; N representing the north pole. The two large arcs of circles on each side of DCL, are the tropics and the small arcs near the poles the *arctic*[4] (northern) and

1. The axis of the earth is at right angles (90°) with the *plane* of the *equator.* The plane of the ecliptic being inclined to that of the equator about twenty-three and one half degrees, it must therefore be inclined to the axis about sixty-six and one half, degrees since sixty-six and one half added to twenty-three and one half equals ninety.

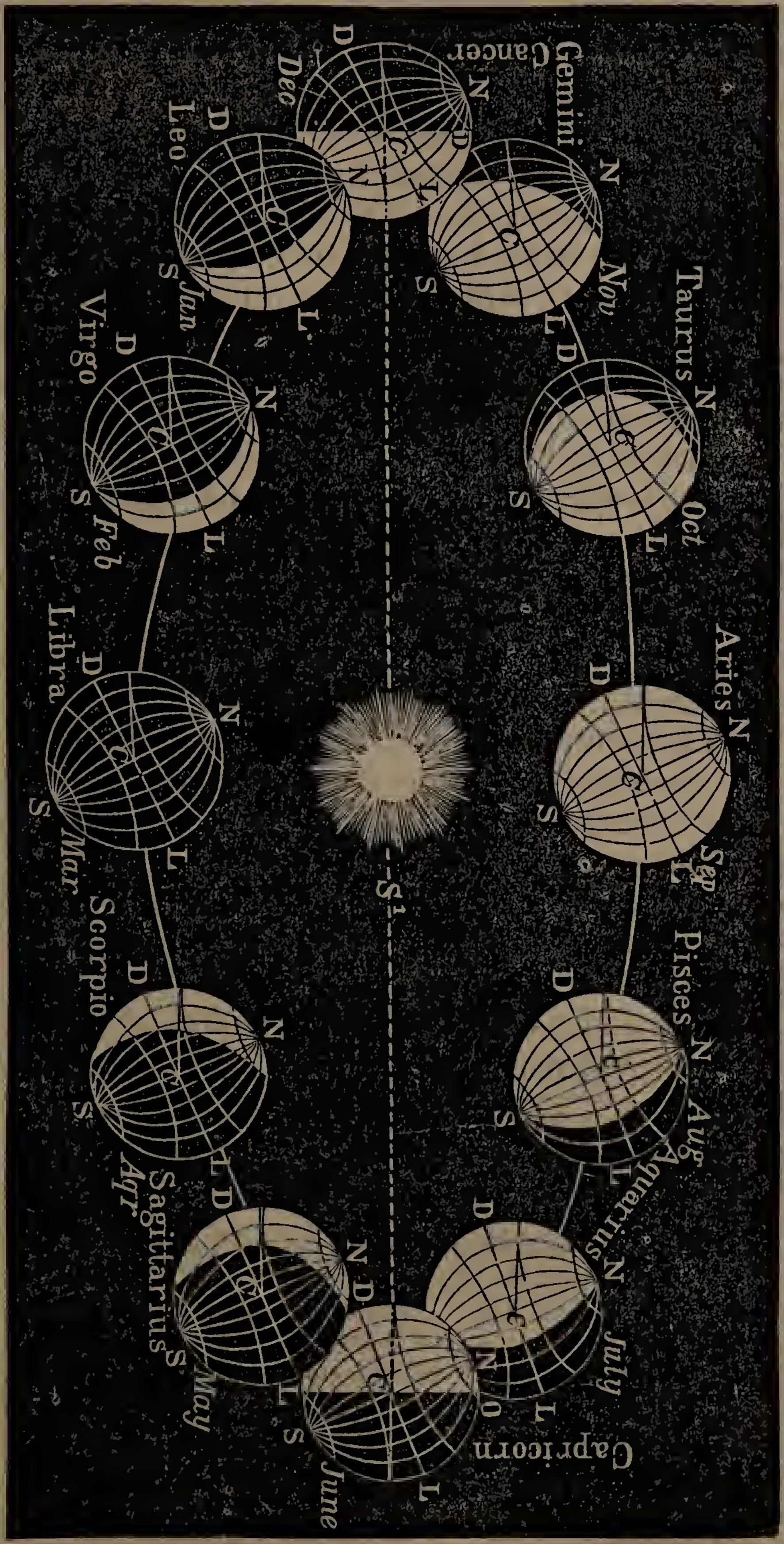
2. *Precession* and *nutation* will of course produce a very slight displacement.

3. The figure is here drawn as if the plane of the ecliptic was viewed *obliquely*, the orbit of the earth therefore, *appears* more *eccentric* than it actually is.

4. *Arctic* (northern.) From the Greek word, *arktos* meaning *bear*, because the *north* pole of the heavens is in the constellation called *the bear.*

What is the extent of the inclination of the earth's axis to the ecliptic? Explain why the earth's axis is directed to the *same* points in the *heavens* notwithstanding the earth revolves about the sun? Explain the figure.

FIG. 40.



THE SEASONS.

antarctic[1], (southern) or *polar circles.* The lines drawn in each globe from C, *parallel* to CS^1C, indicate the *position* of the *plane* of the *ecliptic* with respect to that of the *equator.*

201. SPRING. At the *vernal equinox*, (March,) when the earth is in Libra,[2] the *circle of illumination* extends to the *two poles*,[3] the sun is in the plane of the equator, and is seen from the earth in this plane. As the earth *rotates* on its *axis* every point upon its surface is then *half the time* of *one rotation* in darkness, and the *other half* in *light.* In this position of the *earth*, the *days* and *nights* are therefore *equal* all over the globe.

202. SUMMER. When the *earth* is in *Capricorn* at the *northern summer solstice*[4], (June,) the axis being unchanged in direction, the *north pole* is presented towards the sun, and the *circle of illumination extends beyond the pole* N to the *arctic* (northern) *circle*, while in the *southern hemisphere* it *falls short* of the *south pole* S, reaching only to the antartic (southern) circle.

203. The sun is now seen from the earth in the direction CS^1, having *apparently moved* towards the *north* the extent of the angle DCS^1. This angle DCS^1 *measures* the *inclination* of the *plane* of the *ecliptic* to that of the equator, which is termed its *obliquity*, and is *equal* to about *twenty-three and one half degrees* (more nearly 23° 27′ 37.4″.)

204. The exact distance that the *circle of illumination* now *overlaps* the *northern* and *falls short* of the *south* pole

1. ***Antarctic***, from the Greek ***anti*** opposite, and ***arktos***, bear, i. e., ***south.***

2. At the time of the vernal equinox the earth is in Libra, but the sun as ***viewed from the earth*** appears on the ***opposite side*** of the heavens in the ***sign Aries.***

3. In the figure, at the ***vernal equinox*** the ***dark hemisphere*** of the earth is presented to our view, the illuminated hemisphere being ***toward*** the sun as shown in the globe at Aries. The ***circumference*** of the circle of illumination, both at Libra and Aries is DNLS.

4. ***Solstice***, from the Latin ***sol***, the ***sun***, and ***sto*** I stand, because the sun ***appears*** at the time of the solstices, neither to ***move*** to the ***north*** or ***south***, but to be stationary as respects these ***directions.***

At the time of the vernal equinox, what is the position of the circle of illumination in respect to the poles? In what plane is the sun then situated, and in what plane seen? What is said in regard to the lengths of the days and nights at this time? What is the position of the circle of illumination at the northern summer solstice? What is the obliquity of the *ecliptic*? Its extent?

is *equal* to the *obliquity* of the *ecliptic;* for since the time of the *vernal* equinox, the sun in his *apparent motion* has departed from the plane of the equator at the *same rate*, that the plane of the circle of illumination has departed from the poles[1]. The *parallels* of latitude therefore, to which the circle of illumination extends at the *summer solstice*, and which are termed the *arctic* and *antartic* circles, are each about twenty-three and a half degrees from their respective poles. The regions inclosed within these circles, are called the *frigid zones.*

205. At the time of the *northern summer solstice, continual day* reigns at all those places that are situated within the arctic circle, inasmuch as the daily rotation of the globe does *not carry them without* the *circle of illumination;* while over the *regions* that lie within the antarctic circle, an *unbroken night prevails*, because the earth in its rotation *does not* at this time *bring them within* the *circle* of *illumination.* It is evident from an inspection of the figure, that in the *northern hemisphere*, since half the axis CN falls within the plane of the circle of illumination, that the *days* will *increase* in length and the *nights decrease* from the equator to the *arctic circle*, where there exists a *continual day.* In the *southern hemisphere*, since half the axis CS *falls without* the *plane* of the *circle of illumination* the *days* will *decrease* and the *nights increase* in length from the equator to the *antartic circle*, where an *uninterrupted* night *prevails.*

206. At the vernal equinox, the days and nights as we have seen are *equal* in *length.* A difference in this respect commences as soon as the earth departs from this point, which gradually increases up to the time of the

1. The angles DCN and S[1]CO, are each equal to ninety degrees being right angles. If we take from them the angle S[1]CN which is common to both, the two small angles that remain; namely, NCO and DCS[1] must be equal to each other, but DCS[1] is the measure of the obliquity, therefore, NCO equals 23° 27′ 43.4″. The distance of the circle of illumination from the south pole is proved in the same way, and the same demonstration can be used when the earth is at the northern winter solstice.

The extent of the arctic and antartic circles, and why? What are the Frigid Zones? Where does continual day prevail at the time of the northern summer solstice, and why? Where unbroken night, and why? What is said respecting the lengths of the days and nights in the northern hemisphere? In the southern? When do these differences in length begin?

summer solstice, when the difference in the lengths of the days and nights is greatest.

207. At the summer solstice, the sun's rays fall perpendicularly upon the surface of the earth in the direction S^1C, at a point about twenty-three and a half degrees (23° 27′ 37.4″) north of the equator; the *parallel* of latitude passing through this point is termed the *northern tropic* or TROPIC[1] OF CANCER, because the sun as now seen from the earth appears in the sign Cancer.

208. AUTUMN. As the earth departs from the *northern summer solstice* and by degrees comes round to the *autumnal equinox*, (September,) the circle of illumination gradually approaches the poles, *shortening* the *days* and *lengthening* the *nights* in the *northern* hemisphere, and producing the *contrary effects* in the *southern*. When the earth has arrived at the autumnal equinox in the sign Aries, the *circle of illumination again* passes through *both poles*, and the *days* and nights are once more *equal in length*.

209. WINTER. The earth moving onward in its course toward the *northern winter solstice*, the *circle* of illumination also changes its position *falling short* of the *north* pole *more* and *more*, and *gradually extending beyond* the south pole; *increasing* the *duration* of the *nights* in the *northern hemisphere* and *diminishing* that of the *days*; while in the southern hemisphere the opposite effects are produced. At the winter solstice, when the earth is in the sign Cancer, (December,) this change has reached its full extent; the *circle of illumination* then reaches *beyond* the *south pole* to the *antarctic* circle, and the regions within this circle now enjoy a *continual day*. But in the northern hemisphere the circle of illumination ex-

1. TROPIC, derived from the Greek *trepō*, to ***turn about***, because when the sun, in its ***apparent advance*** to the ***north***, has arrived at a point about twenty-three and one half degrees from the equator, it then ***turns about*** and moves toward the south.

When greatest? How is the position of the northern tropic determined? What is it called? What changes take place as the earth moves toward the *autumnal equinox?* What is said of the *circle of illumination* and of the *days and night* at the equinox? Describe the changes that occur as the earth moves toward the northern winter solstice? At the northern winter solstice what is said in reference to the circle of illumination, and the lengths of the days and nights? Where does there now reign an unbroken day?

tend only to the *arctic circle*, and the space *within the latter* is now *overshadowed* by *a constant night.*

210. As the earth withdraws from the northern winter solstice, and again returns to the vernal equinox, the circle of illumination by degrees again approaches the poles, and the differences between the lengths of the days and nights, grow less and less until they cease to exist, when the vernal equinox is attained.

211. A glance at the figure shows us that the sun at the northern winter solstice is seen *south* of the *equator* in the direction CS¹. And it is seen at this point as far *south* of the *equator* as it was *north*, at the time of the northern summer solstice; viz., 23° 27′ 37.4″. The circle of illumination therefore at the two solstices, *overlaps* and *falls short* of the *same pole* the *same extent of space.*

212. The place where the line S¹C falls upon the surface of the earth south of the equator, is the place of that parallel of latitude, which is termed the southern tropic and which is about twenty-three and a half degrees (23° 27′ 37.4″) south of the equator. It is called the TROPIC OF CAPRICORN.

213. That portion of the surface of the earth included between the *northern* and *southern tropics* is called the TORRID ZONE, and those parts that lie between the two tropics and the *arctic* and *antarctic* circles, THE NORTH and SOUTH TEMPERATE ZONES.

214. We must bear in mind in this explanation that the *winter* of the *northern hemisphere* corresponds in time with the *summer* of the *southern*, and the *winter* of the *southern hemisphere* with the *summer* of the *northern.*

215. POLAR WINTERS—EFFECTS OF REFRACTION. From what has just been stated, it appears that within the polar circle there are long intervals of day and night; while at the poles themselves there is but *one day* and *one night*, each of *six months duration.* But several causes exist which tend to shorten the dreary winter of the

Where an unbroken night? What changes take place as the earth returns to the vernal equinox? How far south of the equator is the sun seen at the northern winter solstice? How much does the circle of illumination at the two solstices *overlap* and *fall short* of the same pole? How is the position of the southern tropic determined? What is its extent? What is it called? What is meant by the Torrid Zone? What by the Temperate Zones? What must we bear in mind? What is evident from the facts that have just been stated?

frigid zones. The principal of these are *refraction* and *twilight*. As already stated, Art 56, the refraction in these regions is *unusually* great, causing the sun to *appear above* the *horizon* when it is *really considerably below it*, and of course *shortening the night*.

216. In the case mentioned on page 59 which happened in the year 1597, three Hollanders were compelled to pass the winter at Nova Zembla in N. Lat. $75\frac{1}{2}°$.

After a *night* of *three months* duration, the sun appeared on the horizon, in the south *fourteen days sooner* than they expected it in *this latitude*, and continued from this time to rise higher and higher in the heavens. If the sun in this instance appeared *fourteen* days *before* it was *really due*, the refraction must have been equal to *three and a half degrees*.

217. Twilight and its Influence. *Twilight*[1] *is chiefly caused by the irregular reflection*[2] *of the sun's rays from the particles of the atmosphere, when the orb is below the horizon;* and it ceases when the sun is below the horizon *more than eighteen degrees*, *measured* on a *vertical circle*. At the *equator* where the circles of daily motion are perpendicular to the horizon, the twilight is the *shortest*, and continues only an *hour* and *twelve minutes*. The *inclination to the horizon* of the sun's *apparent daily path*, affects the duration of the twilight. In all countries *situated between the equator* and the *poles*, the *longest twilight* occurs at the time of the *summer solstice*. In *latitude* 42° 23′ 28″ the longest twilight lasts for the space of *two hours*, *twenty minutes* and *thirty-one seconds*.

218. At *either pole* the sun in its apparent path moves *parallel to the horizon*, and never sinks more than about $23\frac{1}{2}$ degrees below it, but until it has passed lower than 18° the faint glimmerings of twilight do not forsake

1. The twilight that occurs in the morning is called the *dawn*.
2. *Refraction* is a partial cause of twilight, but this phenomenon is *principally* due to reflection.

What causes exist which shorten the winters of the frigid zones? What are the principal? What is said respecting the extent of refraction in these regions? State what was observed at Nova Zembla, in the year 1597. How is twilight caused? When does it cease? Where is the twilight the *shortest?* What is said respecting the *inclination* to the horizon of the sun's path? When is twilight the longest? What is the length of the longest twilight in Lat. 42° 23′ 28′ ?

even these places. The combined effect of *refraction* and *twilight* in shortening the *polar night* is so great that at the *very poles*, its duration is only *seventy days* instead of *six months;* and even the obscurity that then prevails is relieved by the constant presence of the *moon*, when it passes north of the equator; and likewise by the frequent and fitful splendors of the *northern lights.*

219. HEAT—ITS UNEQUAL DISTRIBUTION OVER THE SURFACE OF THE GLOBE—CAUSES. Since the *earth* derives its *heat* chiefly, if not exclusively from the *sun*, it is evident that the *temperature of any region* is intimately connected with the *length* or *shortness* of its *days;* for *during the day* it is *warmed* and cheered by the *solar rays*, but throughout the night, the soil, and most of the objects upon it, *rapidly sink* in *temperature*, on account of the *radiation* of their *heat* into the *cooler* regions of the *atmosphere.* When therefore the *days* are *short* and the *nights long*, the *ground* loses *more heat* in the *night* than it *receives* in the *day*, and *winter prevails.* On the contrary when the *nights* are *shorter* than the *days*, the *earth acquires more heat* than it *loses*, and the seasons of flower and fruit smile upon the land.

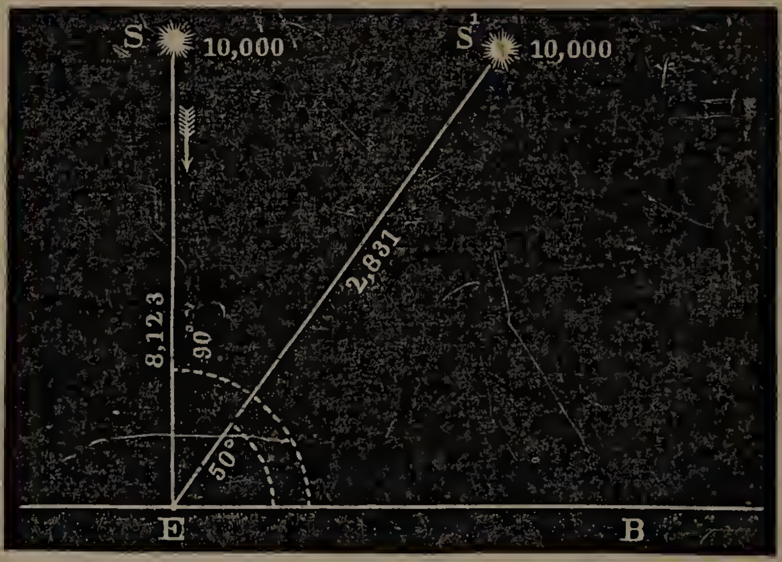
220. *Another cause* of the unequal distribution of heat over the globe is the fact, that the *rays* of the *sun strike* the *surface* of *the earth less obliquely* in *summer than in winter:* thus concentrating *more heat* on a *given surface* in the *former* season, than in the *latter.* From this cause *alone* it has been computed that the *heat* of *summer* would be *nine times greater than that of winter*, if other influences did not exist which lessen the disparity.

221. The refraction due to the atmosphere, must also be taken into account, for according to M. Bouguer, when the sun is *vertical* above any place, 8,123 *rays* out of every 10,000 *actually reach it*, while if this luminary has an elevation of 50°, only 2,831 of every 10,000 arrive at the spot.

State what is said respecting its effect at the poles? What is said of the combined influences of refraction and twilight in shortening the polar night? What other mitigating influences exist? What is the source of the earth's warmth? What is the temperature of any place intimately connected with? Why? When will winter prevail? When summer? State the *second* cause of the unequal distribution of heat? How much hotter would summer be than winter from this cause if there were no counteracting influences? What is the third cause?

222. Thus in Fig. 41, if E represents a *point* on the *surface* of the *earth*, EB the plane of the horizon, S the position of the sun when its rays fall *vertically* upon E

FIG. 41.



LOSS OF HEAT BY REFRACTION.

and S[1] its position when the rays make an angle of 50° with the horizon at E; then 8,123 rays out of 10,000 will reach E when the sun is at S, but only 2,831 when it is at S.[1]

223. SUMMER OF THE SOUTHERN HEMISPHERE NOT HOTTER THAN THAT OF THE NORTHERN. The earth is *nearer* to the sun at its *perihelion* than its *aphelion* by nearly 3,000,000[1] *of miles*, and we should naturally suppose that on this account the *former* would receive at the *perihelion* an amount of heat *sensibly greater than* at the *aphelion.* Moreover since the earth at its *perihelion* is near the *northern winter solstice* when it is *summer* in the *regions south of the equator*, it would seem that the *summer* should be *hotter* in the *southern hemisphere* than it is in the *northern.* It is however found that the *fluctuations* in the earth's *temperature*, from this cause are very *slight*; for the investigations of philosophers have *proved*

1. It will be remembered that the distance of the sun from the earth at the apogee is about 96,000,000 miles, and at the perigee 93,000,000, the difference being 3,000,000.

State what is said respecting its influence, and explain from figure. Why might we suppose the *summer* of the *southern hemisphere* to be *hotter* than that of the *northern?*

that the amount of heat received by the earth is *exactly proportioned* to its *angular velocity* around the *sun.* Therefore since at the *perihelion*, the earth moves through an arc of 61′ in *a day*, and at its *aphelion* through an arc of 57′, the respective *daily amounts* of *heat* received by the earth at its perihelion and aphelion bear the relation of 61, to 57; a variation in temperature so small that its influence upon the climates of the two hemispheres is *inappreciable*, amid other more potent disturbances.

ELLIPTICITY OF THE EARTH'S ORBIT--ITS EFFECT ON THE SEASONS.

224. A slight difference in the length of the seasons is found to exist on account of the ellipticity of the earth's orbit; for, in consequence of the earth moving *faster* in its path according as it is *nearer to the* sun, the time that elapses between the *autumnal equinox* and the *vernal*, is now between *seven and eight days*, (7 days 16h. 2m;) *shorter* than the period embraced between the *vernal* and *autumnal.*[1]

225. The relative positions of the *perihelion* and *aphelion* in regard to the *solstices* and *equinoxes*, at the commencement of the *present century*, are shown in Fig. 42, where E and E¹ represent the *two equinoxes*, EE¹ the *line* of the *equinoxes*, S and S¹ the *two* solstices, and SS¹ the line joining the solstices, A and P are the *aphelion* and *perihelion*, and AP the line of the *apsides.* All these lines intersect at the sun. These *positions* are not *invariable*, for we have seen Art. 183, that the *aphelion* and *perihelion* have a *slow motion* from *west* to *east.* They

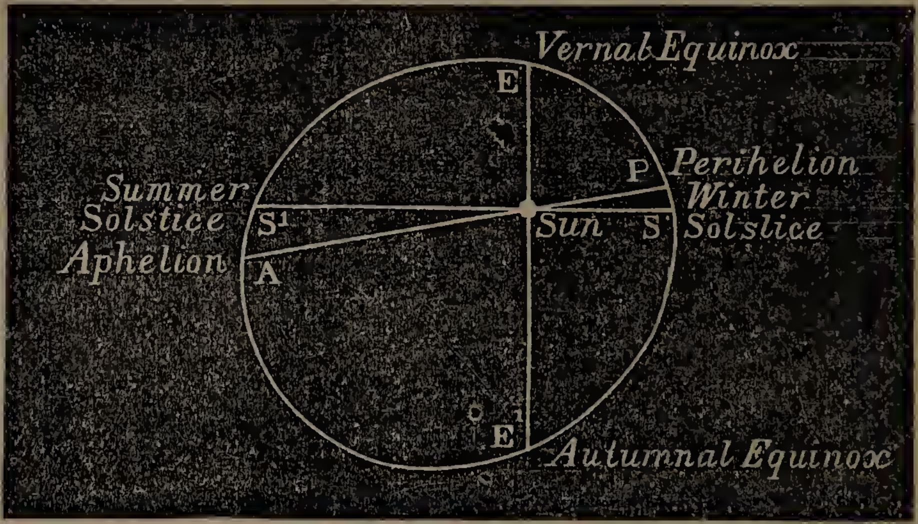
1. In the year 1850, according to Hind, the time that elapsed between,

	days	h.	m.
The ***vernal equinox*** and ***summer solstice*** was,	92	20	57
The ***summer solstice*** and ***autumnal equinox*** was,	93	14	00
The ***autumnal equinox*** and ***winter solstice*** was,	89	17	38
The ***winter solstice*** and ***vernal equinox*** was,	89	1	17

The interval between the vernal equinox and the autumnal, was there fore, equal to 186 days 10h. 57m., and that between the autumnal and vernal, 178 days, 18h. 55m. The difference between these two intervals, is therefore, ***seven days***, ***sixteen hours***, and ***two minutes***.

Explain why it is not? Why does the ellipticity of the earth's orbit affect the lengths of the seasons? How much does the period of time from the vernal to the autumnal equinox now exceed the period from the autumnal to the vernal?

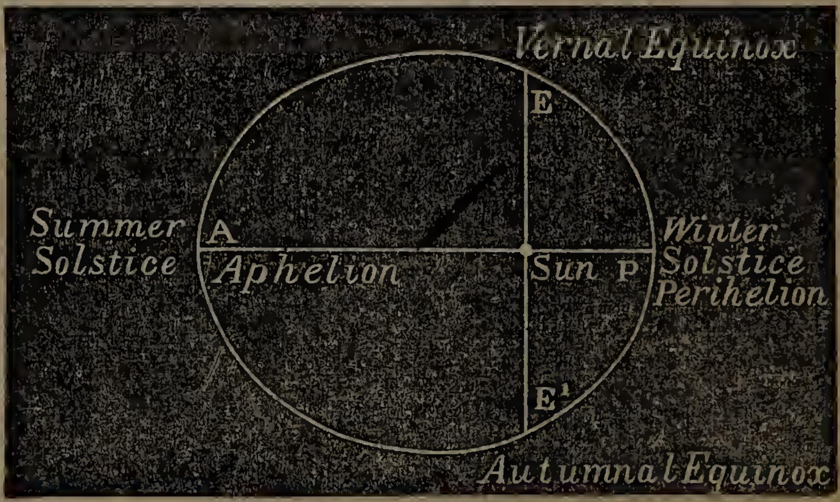
FIG. 42



POSITION OF THE PERIHELION IN THE YEAR 1800, A.D.

will therefore in the course of nearly a thousand centuries Art. 185, *pass round* the *entire orbit* of the earth, and coincide at definite periods of time, with the *solstices and equinoxes*, slightly affecting the *length* of the various *seasons* by this motion. In the year 1,250, the perihelion coincided with the winter, and the aphelion with the summer solstice, as shown in Fig. 43, the construction of which is similar to that of Fig. 42. The spring and winter were then equal in length, and the same was true of summer and fall. A glance at the figure substantiates this statement.

FIG. 43.



POSITION OF THE PERIHELION IN THE YEAR 1250, A. D.

Has the motion of the perihelion and aphelion any effect on the length of the seasons? In what year did the *perihelion* coincide with the *winter* and the *aphelion* with the *summer solstice?* How did the seasons then compare with each other in length?

226. The *perihelion* at the *creation* coincided very nearly with the autumnal *equinox*, a point which can be proved by a simple calculation. In the year 1,250, A. D., the *perihelion* was at the *winter solstice*, i. e. 90° or 324,000″ *distant* from the *autumnal equinox*. Now as the perihelion withdraws from the *autumnal equinox* at the annual rate of 61,53″[1]; it will consequently take as *many years for it* to move *from* the *autumnal equinox to the winter solstice* as *the number of times* that 61,53″ is contained in 324,000″; viz. 5,265. Subtracting then 1,250 from 5,265 we obtain 4,015, the number of years before the Christian era, when the perihelion coincided with the *autumnal equinox*, which is very nearly the date of the creation.

1. The ***vernal equinox*** moves from ***east to west*** at the ***annual*** rate of 50.24″. The perihelion moves from ***west to east*** at the annual rate of 11.29″. These ***two points*** therefore, ***separate*** from each other at the ***yearly*** rate of 61.53″.

Prove that the perihelion nearly coincided with the autumnal equinox, at the epoch of the *Creation*.

PART SECOND.

SOLAR SYSTEM.

CHAPTER I.

THE SUN.

227. We now proceed to describe the SUN, a *vast luminous* and *material globe;* around which a train of *planets* and *comets* revolve, constituting with *the sun* the SOLAR SYSTEM.

228. When the sun is observed through colored glasses, which intercept a portion of its heat and lessen its dazzling brilliancy, it presents the appearance of a *perfect circle*, whose *average angular diameter* is 32′. We are not however to suppose that it is *flat* and *round* like a plate. While we revolve on the earth about the sun, the latter at the *same time rotates* on its *axis*, and yet *always appears round;* a fact which proves it to be a *globe* like our earth, for it is only a *spherical body* that will appear of a *circular form* when viewed from any direction.

229. REAL DIAMETER OF THE SUN. We have seen that the average distance of the sun from the earth is about 95,000,000, (more accurately 95,298,260[1],) and that the average *apparent diameter* is 32′. Knowing these two quantities we are enabled to obtain the actual diameter of the orb, by the method explained in Art. 198.

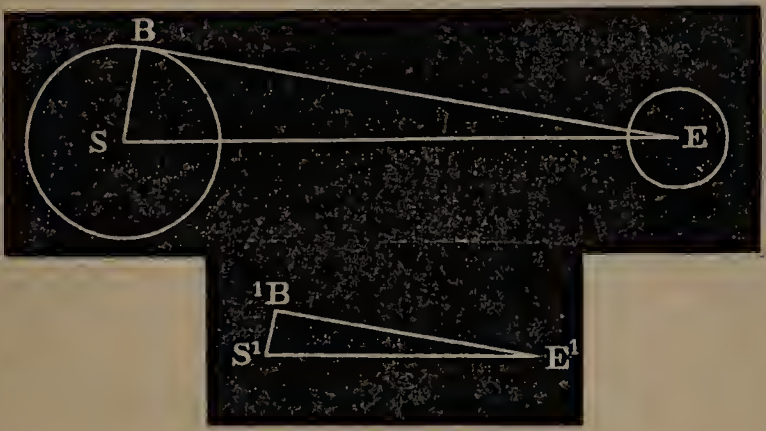
230. In Fig. 44, we represent the *sun* by the *circle* S, *half the sun's diameter* by the *line* SB, the *earth* by the

1. According to the calculations of Prof. Encke of Berlin.

What is the subject of PART SECOND? What of Chapter I.? What is said of the SUN? What *form* does it present when viewed through colored glasses? What is its average angular diameter? Is it flat and round like a plate? What proof have we that it is a *globe?* What two quant'ties must be known in order to ascertain the *real diameter* of the sun?

circle E, and the *distance* of the *centre* of the *earth* from the centre of the *sun* by the *line* ES. which is the *hypothenuse* of the *right angled triangle* SEB.[1]

FIG. 44.



231. We next select from the trigonometrical tables the *values* of the *sides* of a triangle *similar* to SEB. Let $S^1E^1B^1$ Fig. 44, be such a triangle, in which the angle $S^1E^1B^1$ equal to SEB is 16′; $S^1B^1E^1$ equal to SBE is a *right angle*, and $B^1S^1E^1$ equal to BSE is 89° 44′.[2] Now if S^1E^1 is *one mile*, the value of S^1B^1, as shown by the tables, is *four thousand six hundred* and *fifty-four millionths* of a mile, (.004654ths of a mile.) We thus obtain the following proportion, S^1E^1 (1 mile) : SE (95,298,260 miles) : : S^1B^1 (.004654ths of a mile) : the length of SB in miles. Multiplying, therefore, the *second* and *third terms* together, and *dividing* by the *first*, we obtain the following expression for the value of SB, the *radius* of the sun · viz.,

$$\frac{\overset{\text{miles}}{95{,}298{,}260 \times .004654}}{1} = 443{,}518 \text{ miles.}$$

Thus the length of the radius is found. The entire di-

1. SEB is a *right angle*, because when a line as EB is drawn to the *extremity* of a radius of a circle as B, and also *touches* the circle at that extremity, it makes a *right* angle with the *radius*.

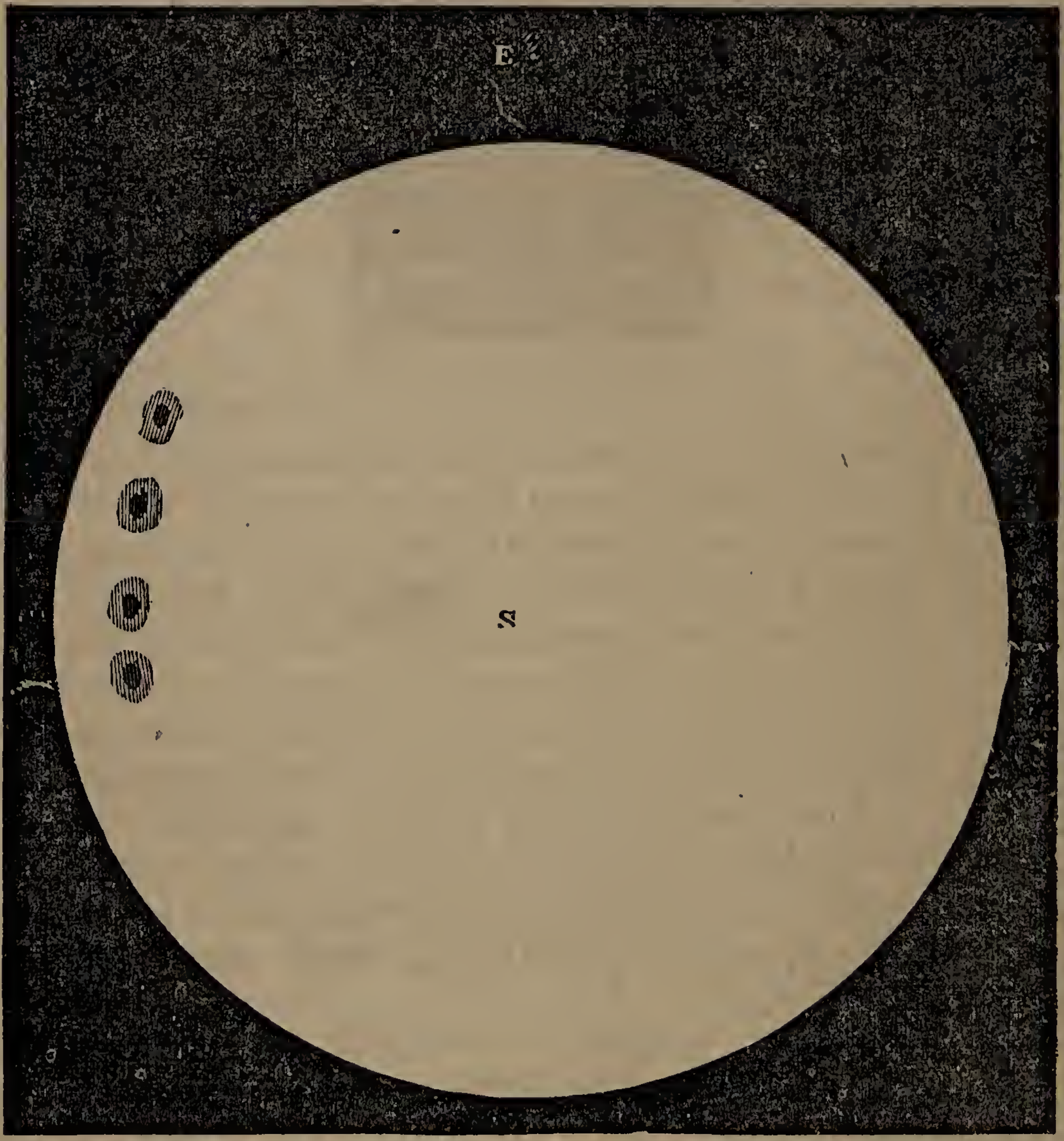
2. Since the *sum* of the three angles in the triangle SEB is equal to 180° (Art. 13,) if the value of SBE and SEB are *known*, their *sum* subtracted from 180° gives the value of the *third* angle BSE.

Find the length in miles of the sun's diameter?

ameter of the sun or *twice the radius*, is therefore, 887,036 miles, nearly *one hundred and eleven* times greater than that of the earth.

232. In Fig. 45, the two circles S and E, represent the

FIG. 45.



RELATIVE MAGNITUDES OF THE SUN AND EARTH.

relative magnitudes of the *sun* and *earth* the *diameter* of the larger circle being 111 *times* greater than that of the *smaller*.

233. Size or Bulk. If we had *two* cubical boxes *A* and *B*, and the *length*, *breadth*, and *height* of A were *severally* 2 *feet*, while the *length*, *breadth*, and *height* of B were *each* 3 *feet*, the size of A, would be found by *multiplying* 2 into itself *twice*, thus, $2 \times 2 \times 2$, the *product* of which is

8. The size of B, would be obtained by multiplying 3 in the same manner, thus, $3 \times 3 \times 3$, the *product* of which is 27. The *numbers* 8 and 27 are respectively the cubes of 2 and 3, and the *size* of the *boxes A and B*, have therefore the same relations to each other, as the *cubes* of their *respective heights, lengths*, or *breadths*.

234. Now mathematicians have proved *that the sizes of spheres are to each other as the* CUBES *of their* DIAMETERS. Calling then the *diameter* of the earth 1, and its *size* 1; and the diameter of the sun 111, the following proportion will give us the *size* of the *sun* compared with *that* of the *earth*,

Cube of the Earth's diameter.	Cube of the Sun's diameter.	size of the Earth.	size of the Sun.
$1 \times 1 \times 1 = 1$:	$111 \times 111 \times 111$: :	1	: 1,367,631;

the last term being obtained by the common rule of three. The sun is thus found to be about *one million four hundred thousand times* (1,400,000) *larger* than the *earth*.

235. QUANTITY OF MATTER IN THE SUN. Astronomers have ascertained from reliable calculations that the *sun* is formed of much *lighter materials* than the *earth*; so much so, that if *four cubic feet* of the *sun's matter* at its average density could be transported to the *surface* of our globe, it would weigh but a trifle more than *one cubic foot* of the *earth's matter* taken at its average density. The quantity of matter in the sun is therefore, about 350,000 *times* ($\frac{1}{4}$ of 1,400,000) *greater* than the *quantity of matter in the earth*.

236. WEIGHT OF BODIES AT THE SURFACE OF THE SUN. A body which weighs 100lbs. on the *surface of the earth*, would, if transported to the *sun*, weigh nearly 2,800lbs. The *weight of a body* on our globe, or on any other, is a *measure* of the *force with which it is drawn toward the centre of the globe*;[1] and when the globes *vary in size*, the magnitude of this force is dependant upon *two circumstances*. FIRST, the *relative quantities of mat-*

1. This *force* is called the *force of gravity*.

Explain how the *size* of the sun is ascertained? How much larger is it than the earth? Is the *matter* of the sun lighter or heavier than that of the earth? How much lighter? How much more matter is there in the sun than in the earth? If a mass of matter weighed 100lbs. on the surface of the earth, what would be its weight on the surface of the sun? What is the weigh of a body the measure of?

ter in the *two bodies;* SECONDLY, the *comparative distances* of the *surfaces* of the globes *from their respective centres.*

237. If there were two globes M and N, and N contained *ninety times as much matter* as M, it would in virtue of this *greater amount of matter* draw any body placed upon its surface, down toward its centre, with *ninety* times more power than if the same body was placed on the surface of M. But if the *distance* from N's *centre* to its *surface* was *three times greater* than the distance of M's *centre* from its *surface*, the body placed on N's surface would in virtue of this circumstance be drawn toward the centre with *nine* (3×3 the square of 3) times *less power* than when placed upon M's surface. By being removed from M to N, the *weight of the body* would therefore be *increased* 90 *times*, and *diminished* 9 *times*[1]; which is the same as saying that the *weight of the body* would be *increased* 10 *times.*

238. Now to apply this rule to the sun. If a mass of matter which weighs a pound at the surface of the earth were to be transported to the *surface of the sun*, its weight would be *increased* 350,000 *times* in consequence of the greater *amount of matter in the sun;* and *diminished* 12,321 *times* (111×111,) because it would be removed 111 times *farther* from the *centre of the body* on which it then rested, than when at the earth. *Multiplying* therefore, 1 by 350,000, and *dividing* this product by 12,321 the quotient is 28.4, which is the *weight in pounds* of the given mass at the *sun's surface.* A body therefore, which weighs one *hundred* pounds at the surface of the earth would weigh about *twenty-eight hundred* pounds at the surface of the sun. A person weighing at the earth 150lbs. would weigh at the sun nearly two tons.

1. This rule is *technically* expressed by saying that the *force of gravity varies directly* as the *quantity of matter* in the *attracting* body and *inversely* as the *square* of the *distance* from its *centre.*

Upon what *two circumstances* does this force depend? Give the explanation. What is the *law* respecting this force, in relation to the *quantity of matter?* What in relation to the distance from the *centre* to the surface of the attracting globe? Apply the rule found to the sun?

SOLAR SPOTS.

239. When the sun is viewed through a telescope furnished with dark colored glasses, and its brilliancy is thereby so much diminished that the eye can gaze upon it without injury, *dusky spots* are usually seen upon its surface, extending about 35° degrees on *each side* of the *sun's equator*. Each spot consists of two parts, the *central portion* or *nucleus*,[1] which is the *darkest*, and around this is a *lighter shade* called the *penumbra*,[2] *usually* having the *same form as* the spot, though this is not always the case, as several spots are at times included within the same penumbra.

240. The spots are not *permanent*, for they are sometimes seen bursting out *suddenly* from the bright disk[3] of the sun, and then as rapidly *disappearing;* one observed by Hevelius *appeared* and *vanished* within *seventeen hours*. Their *form* and *size* also *vary* from *day to day*, and even from *hour to hour*. Sometimes they are seen to *divide* and *break up* into two or more *separate portions*.

241. SIZE AND NUMBER. The *extent* and *number* of spots almost exceed belief, M. Schwabe of Dessau, who has examined them with great attention, has discovered many *without* the *aid of the telescope*. In June 1843, one was seen by him with the *naked eye*, for the *space of a week*, which measured 167″ *in breadth*. Now as the entire *angular diameter* of the sun is 1,920″ (32′ × 60) and its *real diameter* about 887,036 *miles* we can readily find by the rule of three the *real breadth* of the *spot* in *miles;* for 1,920 : 887,036 : : 167 : 77,153. The breadth of the spot was therefore about 77,000 miles, nearly TEN TIMES as broad as the earth. Another mentioned by

1. ***Nucleus***, from the Latin word ***nucleus***, a kernel.
2. ***Penumbra***, from the Latin ***pene***, almost, and ***umbra***, a shadow, i. e., *a light shade*.
3. ***Disk***, the *face* of the sun, moon or a planet, as seen from the earth, from the Latin word ***discus*** a quoit.

What have been detected upon the sun's disk? Upon what part of the disk are they found? Describe the spots? Their changes? Within what time has a spot been known to appear, pass through its changes and *vanish*? What is said respecting of their size and number? Who has examined them with great attention? What has he discovered? How large a spot did he behold in June, 1843. Calculate its extent? How did it compare in breadth with the earth?

Sir John Herschel, had a diameter of 45,000 *miles.* This gentleman also observed at the Cape of Good Hope, toward the close of March, 1837, a *cluster* of spots that covered a space 3,780,000,000 miles in extent; an area *nineteen times greater than the entire surface of our globe.*

242. These *groups* often comprise a great number of individual spots. M. Schmidt, of Bonn, counted no less than *two hundred* in a large cluster that he examined on the 26th of April, 1826, and in August of the preceding year, he detected *one hundred and eighty* in a single group. It is a remarkable fact that although the spots extend over such vast spaces, they seldom last more than *six weeks.*

243. The *number of spots* varies much in different *years.* It occasionally happens, that during an entire year, spots may be seen upon the sun *every clear day*, while during another year it will be *free from* them for *weeks*, and even *months* together. M. Schwabe, who has closely observed the sun for the space of *twenty-five years*, has clearly established this fact; for he found that in the years 1836–7–8 and 9, there was not a *single day* on which the sun was free from spots, while in 1843, there were no less than 145 *clear days* when *spots could not be seen.*

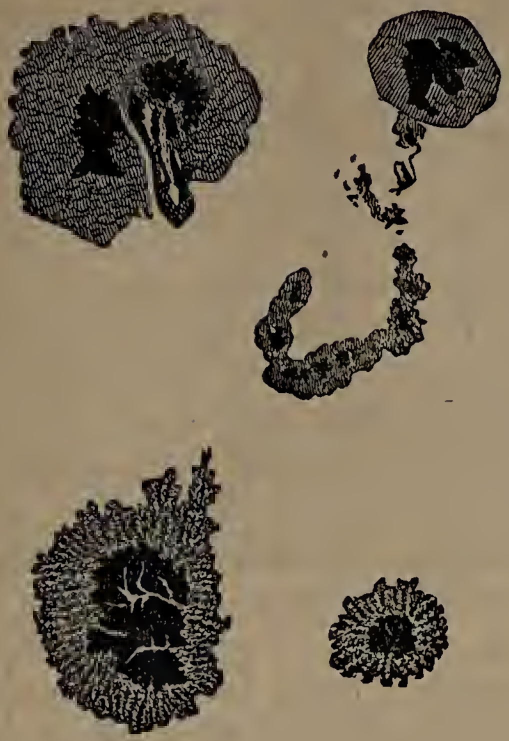
244. In addition to the spots the disk of the sun is also diversified by *branching ridges* and *streaks more luminous* than the general surface. These brilliant lines are usually found in the *vicinity* of vast spots and clusters, and from their midst the spots themselves not unfrequently break out and spread.

In Fig. 45, four spots are delineated on the solar disk, and in Fig. 46, *spots* and *clusters* are shown under their various appearances, the *nucleus* in each being represented by the *darkest* part, and the *penumbra* by the *lightest.*

245. MOTION OF THE SPOTS. If the sun is watched attentively from *day to day* a spot at its *first* appearance will be perceived on the *east side* of the sun, and is then

Give other instances of the magnitude of spots, and groups of spots? How many individual spots do the groups sometimes comprise? Does the number of spots vary in different years? Give instances. How is the sun's disk otherwise diversified? What is stated in respect to these brilliant lines? On what side of the sun does a spot *first* appear?

FIG. 46.



SOLAR SPOTS.

seen to move gradually *across the solar disk*, until at length it *disappears* on the *western side*. In this passage it occupies about a *fortnight*, which is the *period of its visibility*. After the *same lapse of time* it *reappears* on the eastern edge.

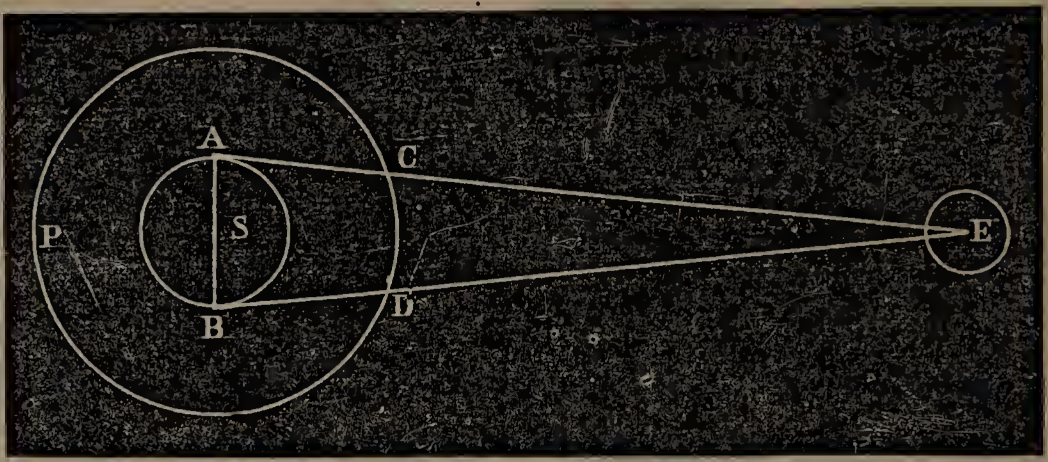
This is true with respect to *all spots* which have *been observed for this purpose*, and whose *returns* have been *noted;* and the fact that their periods of *visibility* and *invisibility* are *equal*, *proves that the spots are in contact with the sun*. For if they were at any considerable distance from the body of the sun, the *time of their visibility* would be *less* than that of their *invisibility*, as can be easily shown by the aid of Fig. 47.

246. In this figure the circle E represents the *earth*, and circle ASB the *sun*. Now if *a spot was not in contact with the sun's surface* but moved in the large circle CDP; it is obvious that it would be *impossible* for a person at E to see it crossing the sun's surface *except while*

How does it move, and where *disappear?* What is the period of a spot's *visibility* and *invisibility?* What is proved by the equality of these periods?

it was passing through the arc DC. At D and C the spot would *appear* on the *edges* of the solar disk at B and A,

FIG. 47



SOLAR SPOTS—PERIODS OF VISIBILITY AND INVISIBILITY.

and it would be *invisible all the time* it was passing from C *through the rest of the circumference of the large circle,* round to D again. Now as the *arc* CD is much smaller than the other part of the circumference of the large circle; to wit, CPD, the spot, if it moved uniformly must be *visible* for a *much shorter time* than it is *invisible, which is not the case.*

But if the spot is upon the surface of the sun, it will take as *long a time for it to move from B to A* toward E, *as from A* round to B again; since the diameter ASB *divides* the circumference of circle S into *two equal parts.* The *times of visibility* and *invisibility* must consequently now be *equal;* a conclusion in *accordance* with *all observations.*

247. The *time that elapses between the appearance* of a spot at any point on the solar disk, and its *reappearance* at the *same point,* is therefore about *four weeks,* (more nearly $27\frac{1}{4}$ days.) A spot was observed in the year 1676, A. D., which made nearly *three revolutions.*

248. Rotation of the Sun of its Axis. It is by means of the *solar spots* that the *rotation of the sun on its axis* is *ascertained,* and the *period* of its *rotation* deter-

Show from the figure why the spots must be in contact with the sun? How long a time elapses between the appearance and reappearance of the same spot at the same point on the sun's surface? How many revolutions has a spot been known to make?

mined. The *equality* in their times of *visibility* and *invisibility*, and the *uniform direction* they pursue in their passage across the sun's disk, lead to the conclusion that the spots have *no motion*[1] of their own; but, being connected with the body of the sun, are all carried forward from *west to east* by the rotation of this great orb on its axis. Astronomers have differed somewhat in respect to the *period* of *rotation*, but the best and most careful measurements show that the sun *rotates once* on its *axis* in the space of 25 days 7h. 48m.

249. This period is *less* than that of the revolution of the spots, and the reason is evident. If a spot is noticed *just on the eastern margin* of the sun by a spectator upon the earth, it will not *reappear* upon the *same margin* when the sun has completed one rotation. For while the sun has been performing a revolution on its axis the earth has also been advancing in its orbit, and the eastern margin of the sun is now as *many degrees* and parts of a degree to the *west* of what was the *eastern margin* when the spot first appeared, as the earth has *advanced degrees* and parts of a degree *in its orbit, during a rotation of the sun.* This angular space over and above a complete rotation *must be gained* before the spot will be seen from earth, *reappearing on the eastern edge of the sun.*

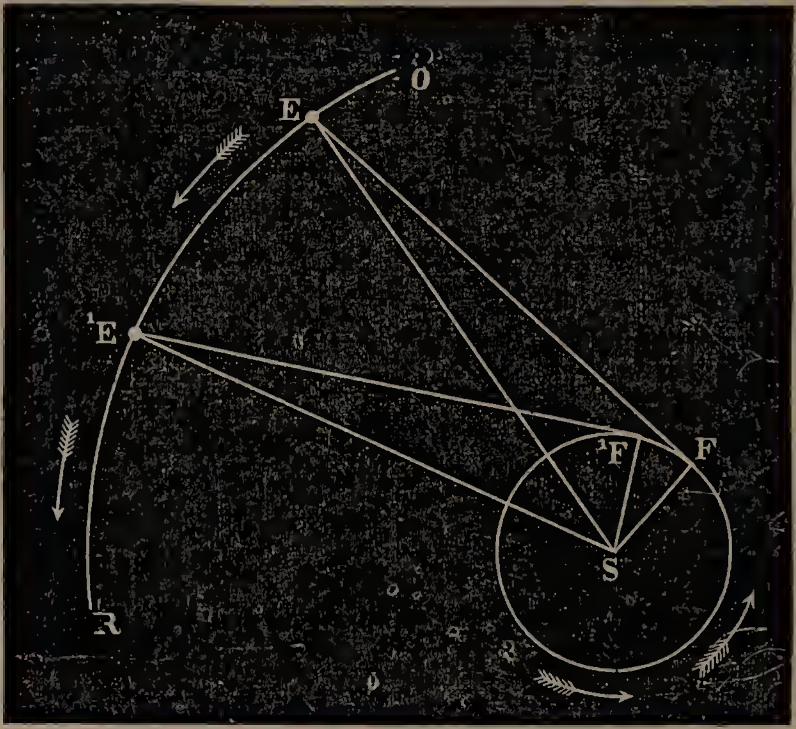
250. This point is illustrated by Fig. 48. In this figure the circle S represents the sun, and OR a portion of the earth's orbit. When the earth is at E, F is a point on the *eastern margin* of the sun; but when at E¹, F¹ is on the *eastern margin.* Now if the earth was stationary at E, and a spot appeared first at F, it would remain visible for a time, then *disappear*, and at length *reappear* at F, when the sun had made *exactly one rotation.*

But the earth is *not stationary*, for while the sun is *rotating once* it advances as far, we will suppose as E¹

1. Some astronomers however, have thought that the spots *change their position* on the sun's surface.

How is the rotation of the sun on its axis ascertained, and the time of the rotation determined? Are the spots supposed to have a motion of their own? What is their motion the same as? In what time does the sun complete a rotation? Is this period equal to that of the revolution of the spots? Explain why they differ? Explain from figure 48

FIG. 48.



PERIOD OF THE SUN'S ROTATION.

The spot will *not* therefore *reappear* when it has arrived at F, and the sun has made *one rotation*: the sun must revolve still more until the spot has arrived at F[1], when it will be seen by the spectator at E[1] on the eastern margin of the sun; the *same place* that it occupied when seen at F from E. The *time therefore that elapses between the appearance* and *reappearance* of a spot *is the time it takes the sun to perform one rotation, and such additional part of a rotation as is represented by the angle FSF.*[1] Now the angle FSF[1] is *equal* to the *angular motion of the earth* in its *orbit*, while passing from E to E[1]; viz., the angle E[1]SE;[1] a quantity which is *known*, since the time the earth takes in passing from E to E[1] is *exactly* the *same* as that which elapses between the *appearance* and *reappearance* of the *same spot;* viz., about $27\frac{1}{4}$ days.

251. An approximation to the period of the sun's ro

1. The triangles EFS and E[1]F[1]S being in *every respect equal*, the angles E[1]SF[1] and ESF, are therefore equal. Taking from these the angle ESF[1] which *belongs to both*, the remaining angles ESE[1] and FSF[1] *must also be equal* to each other.

Knowing the period of time that elapses between the *appearance* and *return* of a spot, how do we obtain the time of the sun's rotation?

tation may be thus obtained. The earth moves from E to E^1 in nearly $27\frac{1}{4}$ days, at the *rate of about one degree* a day; the angle ESE^1 is therefore nearly *equal* to $27\frac{1}{4}°$, and so is FSF^1. Consequently the sun in $27\frac{1}{4}$ days performs *one rotation* (360°) and *the additional part* FSF^1 ($27\frac{1}{4}°$.) We then have the following proportion. The *angular space* through which the sun rotates in *twenty-seven and a quarter days*; to wit, $387\frac{1}{4}°$ *is to* $27\frac{1}{4}$ days *as* 360° *is to* the *period* of *one rotation.* Multiplying next the *second* and *third* terms and dividing by the *first*, thus

$$\frac{360 \times 27\frac{1}{4}}{387\frac{1}{4}}$$

the value of the fourth term is found to be $25\frac{1}{3}$ days. The period of rotation is therefore, about 25 days 8h. More refined calculations give the period before mentioned; viz., 25 *days* 7*h. and* 48*m.*, as the true time of the sun's rotation on its axis.

252. INCLINATION OF THE SUN'S EQUATOR TO THE PLANE OF THE ECLIPTIC. If the *equator* of the sun was *coincident* with the *plane* of the *ecliptic*, it is clear that the *path of the spots* across the disk of the sun would appear as *straight lines*, when viewed from the earth in *any point of its orbit.*

If the *plane* of the sun's *equator* was *perpendicular* to that of the *ecliptic*, it is manifest that in *two opposite* positions of the earth and in two *only* would the paths of the spots appear as *straight lines*; viz., when the *plane of the sun's equator passed through* the earth: and when the *poles of* the *sun's axis* were *directed* to the earth, the spots would be *visible* throughout their *entire revolution*, and would describe *complete circles.* But the spots present no such *phenomena* in their passage across the sun, consequently the *plane of the sun's equator* is *neither perpendicular to* nor *coincident with that of the ecliptic.*

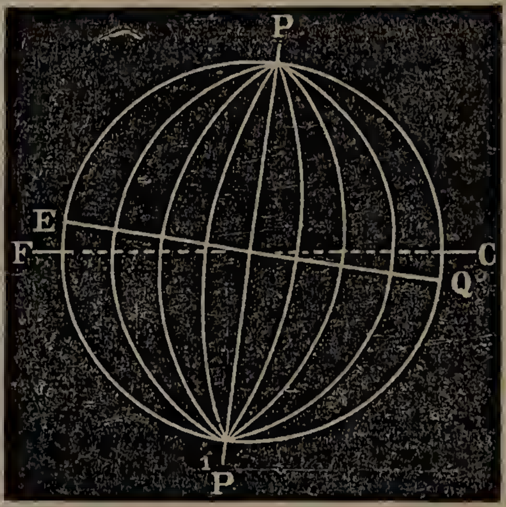
253. The *paths* of the spots however *vary* when viewed from *different points* of the earth's orbit. At the close of November and the beginning of December they appear as *straight lines.* They then gradually assume *more and more* of an *oval* shape being *most curved*

State what would be the form of the *paths* of the spots if the equator of the sun was *coincident* with the plane of the ecliptic? What if *perpendicular*?

about the first of March. From this time their *curvature diminishes*, until the last of May or the first of June, when they again appear as *straight* lines. They pass through the *same changes* for the *next six months*, with this *difference*, that the *curves are now* in a *direction opposite* to that which took for the six preceding months.

254. By observing the changes in the paths of the spots with great attention, astronomers have been enabled to ascertain the *position* of the *solar equator* with reference to the *plane of the ecliptic*, and the result is that the *former* is inclined to the *latter* at an angle of about *seven and a quarter degrees*; as shown in Fig. 49, where PEP'Q represents the *sun*, PP' its *poles* and EQ its

FIG. 49.



INCLINATION OF THE SUN'S EQUATOR TO THE ECLIPTIC.

equator, which makes with FC, the direction of the *plane of the ecliptic*, an angle of about $7\frac{1}{4}$ degrees.

255. Physical Nature of the Sun. Various opinions have been entertained by astronomers respecting the *constitution* of this immense body. La Place considered the sun to be a *fiery globe* of *solid materials*, subject to terrible volcanic action; and that the *spots* are *deep cavities*, from whence issue at intervals vast floods of burning matter which pour over the surface of the sun.

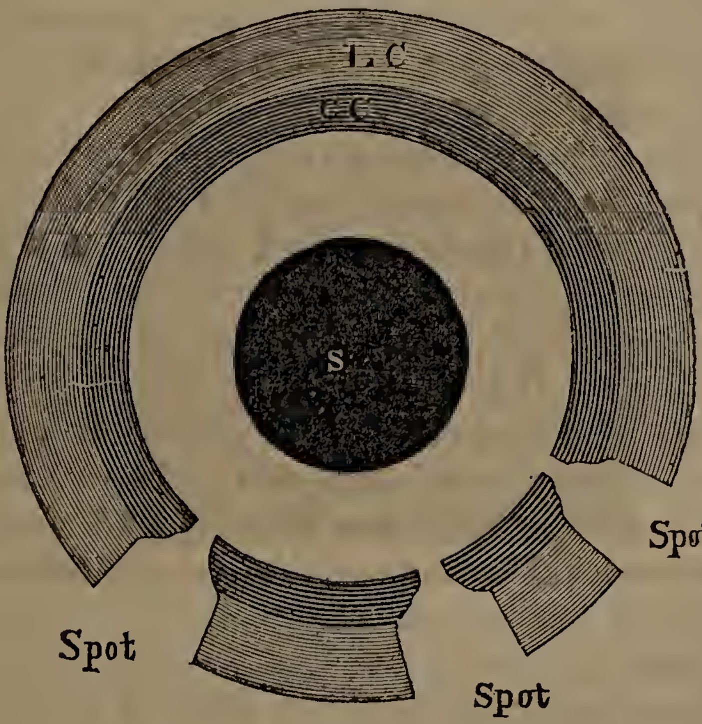
256. Sir William Herschel, regards the sun as a *dark*

Describe the paths *actually* pursued by the spots? How is the inclination of the sun's equator to the plane of the ecliptic determined? How much does this inclination amount to? State La Place's opinions respecting the constitution of the sun?

solid body, surrounded at a *considerable distance* by a stratum of *cloudy matter*, *above* which and *nearest to us* floats an *intensely hot* and *luminous* atmosphere. Whenever these two envelopes, the *cloudy* and the *bright*, are agitated by any causes existing in the sun, it frequently happens, that they are *rent asunder*, and we perceive *through the opening* the *dark body* of the *sun*. Under these circumstances a *spot appears*. The *black portion* of the sun disclosed, is the *nucleus* of the *spot*, and the *portions* of the *cloudy stratum illumined* by the *light* from the *luminous canopy* form *the penumbra*.

257. In Fig. 50, a section of the sun is delineated

FIG. 50.



THE SUN—HOW CONSTITUTED.

as it would appear if Herschel's views are *true*. In this cut the *dark circle* S, represents the *body of the sun*, the *deeply shaded ring* CC the *cloudy canopy*, and the *outer ring* LC, of a *lighter shade*, the *luminous stratum*. The *ruptures* in the rings are the *places of the spots*. Looking through any of these openings a *portion* of the *dark* body of the sun would be seen in the centre, form-

State Herschel's, and describe figure

ing the *nucleus*, while the *shelving edges* of the *cloudy stratum* would constitute the *penumbra*.

258. The theory of Sir William Herschel, affords as satisfactory an explanation of the phenomena of the sun as any that has been advanced. Spots 45,000 and even 77,000 miles across, close up in *six weeks*. The edges must therefore approach each other with a *joint velocity*, varying from *one thousand* to nearly *two thousand miles a day*; a swiftness of motion which agrees better with the idea, that the spots are *ruptures* in *fluid* or *gaseous* matter, than that they are *cavities* in a *firm* and *solid mass*.

But a late experiment of a French philosopher has now proved, that the *brilliant visible surface* of the sun *can not consist* of either *solid* or *fluid* matter intensely heated, but is composed of *inflamed gaseous* matter; a fact which strongly corroborates Herchel's views. We will state what this experiment is.

259. If we look through a polarizing[1] telescope at any *solid* or *liquid body intensely heated* to *whiteness* it *invariably* presents to the eye two *colored* images of the *body*, but if we gaze through the *same instrument* on *burning gaseous* matter, as a gas-light, we *always* see on *the contrary*, two *colorless* images. Now on viewing *the sun* directly with a polarizing telescope *two images* of the sun are seen of *equal brightness* and *destitute of color*. Thus showing that the exterior visible surface of the sun neither consists of *solid* nor *liquid matter intensely heated*, but that it is of a *gaseous* nature.

260. TEMPERATURE AT THE SUN'S SURFACE. In gazing then upon the sun, we look not according to Herschel's theory upon the *body itself*, but on the *canopy* that *envelopes it*; and from the latter flows all the *light* and *heat* that cheer and invigorate the various orbs that revolve around this vast luminary.

261. The *temperature* at the sun's visible surface is

1. The subject of the polarization of light can not here be discussed on account of its length. It can be found in any good text book on Natural Philosophy.

Give the reasons why Herschel's theory is most satisfactory? How is the sun's surface proved not to consist of either solid or liquid matter intensely heated? From whence do the solar light and heat emanate? What is said respecting the temperature at the sun's surface?

very great, for the hottest fires that rage in the fiercest furnaces but feebly shadow forth the heat that there prevails. It can be shown, from reliable calculations, that if a given surface, as one *square mile*, receives at the *distance* of the *earth from the sun* a *given amount of heat;* that the *same extent* of *surface at the sun* must be *three hundred thousand times hotter.* Moreover the *brightest flame* man can produce, as the Drummond light, (which is so dazzling that it is painful to look upon,) appears as a *dark spot* upon the sun, when placed between the eye and the solar disk, being virtually *extinguished* by the sun's surpassing splendor.

CHAPTER II.

THE MOON.

262. This beautiful orb is a constant attendant of the earth in its circuit about the sun, revolving meanwhile in the *same direction* from *west to east around* the *earth* as its *centre.* Her influence upon our globe, is by no means unimportant. Equal in *apparent* size to the sun, her mild splendor dissipates the shades of night, while her attractive power sensibly affects the *motions of the earth*, and sways the *tides of the ocean.*

263. Distance. This orb is the *nearest to us* of all celestial bodies, her *average distance* being about 239,000 miles. The measurement of this distance is obtained in *the same* way as the distance of the earth from the sun. The *parallax* of the moon is found to be about 57′, and the length of the earth's radius being known, the calculation is made as follows.

264. Let M Fig. 51, represent the *centre* of the *moon*, E the surface of the *earth*, O its *centre*, OE a *radius;* and MO and ME, lines drawn from the *moon's centre* to the

How ***much hotter*** is a *given surface* at the *sun* than at the *earth?* What is said respecting the *splendor* of the solar light? What is the subject of Chapter Second? What is said respecting the motions of the moon, and her influence upon our globe? What is said in regard to her distance from the earth? How *far* is she from the earth? How is her distance in miles ascertained? What is the amount of her parallax?

earth's *centre* and *surface;* we thus have a triangle in which MEO is a right angle, EMO 57′, and MOE 89°

FIG 51.

MOON'S DISTANCE MEASURED.

3′.[1] We now select a *similar triangle;* suppose M¹E¹O¹ to be such a triangle, and that the side M¹O¹ *is one mile long*, then the trignometrical tables show us that O¹E¹ must be *sixteen thousand five hundred and eighty millionths of a mile long* (.016580,) and we establish from the sides of the similar triangles the following proportion; to wit, .016580 (O¹E¹) : 1 (M¹O¹) : : 3956.2[2] (OE) : 238,613 miles (MO.) The *fourth* term, found by the common rule of three, is the *distance of the moon from the earth's centre measured in miles.* When all the niceties of calculation are introduced into the computation the *average distance* is found to be 238,650 miles.

265. Diameter in Miles. In the same manner the *diameter of the moon in miles* is ascertained, when we have *first* learned her *distance in miles.* For if we represent the *moon's centre*, Fig. 52, by L, and the earth's by E, and imagine *two lines* drawn from the centre of the earth; the *one* to the moon's surface at S, and the *other* to her centre, these lines will form with the moon's *radius* LS a *right angled triangle;* whereof ESL is the *right* angle, SEL the *apparent semi-diameter* of the moon, equal to 15′ 40″[3] and LE the *moon's distance from* the

1. The *sum* of the angles MEO and EMO *subtracted* from 180° gives a remainder of 89° 3′; i.e. *the value* of MOE.

2. The mean length of the radius of the earth is 3956.2 miles.

3. The *mean* apparent diameter of the moon according to Hind is 31′ 20″.

Explain from the cut how the distance is calculated? What is the exact distance? Show how the diameter of the moon *in miles* is ascertained?

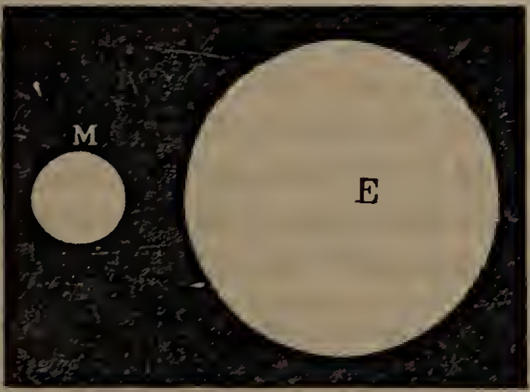
FIG. 52.

MOON'S DIAMETER IN MILES.

earth; all *known quantities.* Selecting then a *similar triangle;* viz., $L^1S^1E^1$, and regarding L^1E^1 as *one mile long*, we find that according to the table the length of L^1S^1 is *four hundred and fifty-six hundred thousandths of a mile* (00456ths.) We then make this proportion; to wit, $(L^1E^1)\ 1 : (S^1L^1)\ .00456 : : (LE)\ 238{,}613 : 1088$. *Half the diameter of the moon therefore measures* 1088 *miles*, and the *entire diameter* is 2176 miles, which is nearly its true length.

When the calculation is carried out with the greatest exactness, and every refined correction made, the moon's diameter according to Prof. Mädler is found to be 2,160 miles long; an extent a little greater than one fourth of the *earth's diameter.* The *relative sizes* of the *earth* and

FIG. 53.



RELATIVE SIZES OF THE MOON AND EARTH.

moon are shown in Fig. 53, where E represents the *earth* and M the *moon.*

What is the extent of the diameter?

MOON'S PHASES.

266. The moon has no light of her own, but shines by the *reflected light* of the sun, the hemisphere presented to the sun being *illumined* with his rays while that which is turned from him is *shrouded* in *darkness*. The *relative positions* of the *sun*, *moon*, and earth are not *always* the *same*, and hence arise those changes in the appearance of the moon which are termed *phases*.[1]

FROM NEW MOON TO THE FIRST QUARTER.

267. At *new moon* the *centres* of the *sun*, *moon*, and *earth*, are situated in nearly the *same straight line*, the *moon* being now between, at which time she is said to be in *conjunction*. In this position the *unenlightened* part of the moon is *turned towards* the *earth*, and the orb is lost to our view. In a short time it advances so far to the *east* of the *sun* as to become visible in the *west* soon *after his setting*. Its bright portion then appears of a *crescent* form, on that side of the disk which is *nearest* to the sun, while the remaining dark part of the disk is just discerned, being faintly illumined by the earth-light.[2] In this position the *convex part* of the moon's crescent is *towards* the *sun*, and the *line* which *separates* the *illumined* from the *unillumined* part, called the *terminator*, is *concave*.

268. Each succeeding night the moon is found farther eastward of the sun, and the bright crescent occupies more and more of her disk, the terminator gradually growing less *curved*, until when the moon is 90° distant from the sun, half the disk is illuminated and the *terminator* becomes a *straight line;* the moon is then *in her*

1. ***Phases*** from the Greek word *phasis*, meaning an appearance.

2. ***Earth-light.*** Some of the *light* which falls upon the earth from the sun is *reflected* to the *moon*, and a portion of this is *reflected back* again from the *moon's surface to the earth*. This is the *earth-light*. The amount thus reflected from the lunar surface must necessarily be very small, but it is sufficient to enable us faintly to discern the outlines of the moon.

Does the moon shine by her own light? What is the *cause* of the changes in the appearance of the moon? What name is given these changes? Describe the phases of the moon from new moon to the first quarter.

FIRST QUARTER. The *extremities* of the moon's crescent are called *cusps*,[1] and from the time of new moon to the first quarter the moon is said to be *horned.*

FROM THE FIRST QUARTER TO FULL MOON.

269. As the moon *advances* beyond her *first quarter*, the *terminator* becomes *concave toward* the *sun* and more than half the lunar disk is illuminated, when the moon is said to be *gibbous.*[2] At length in her *easterly* progress, she reaches her *second quarter*, and the *sun*, *earth*, and moon are *again* in nearly the *same straight line;* the *earth* however being now between. The moon is now in *opposition*, 180° from the sun, *rising in the east* at about *sunset;* and as her *whole* enlightened *disk* is *turned toward the earth*, she is now at the FULL.

FROM FULL MOON TO THE THIRD QUARTER.

270. After *opposition* the *enlighted* part of the moon again becomes *gibbous* as she returns toward the sun; and she rises later and later every night. When she has arrived within 90° of the sun, she is then in her THIRD QUARTER, the terminator is once more a straight line, and the bright portion of the orb again *fills up* one *half* of *the disk.*

FROM THIRD QUARTER TO NEW MOON.

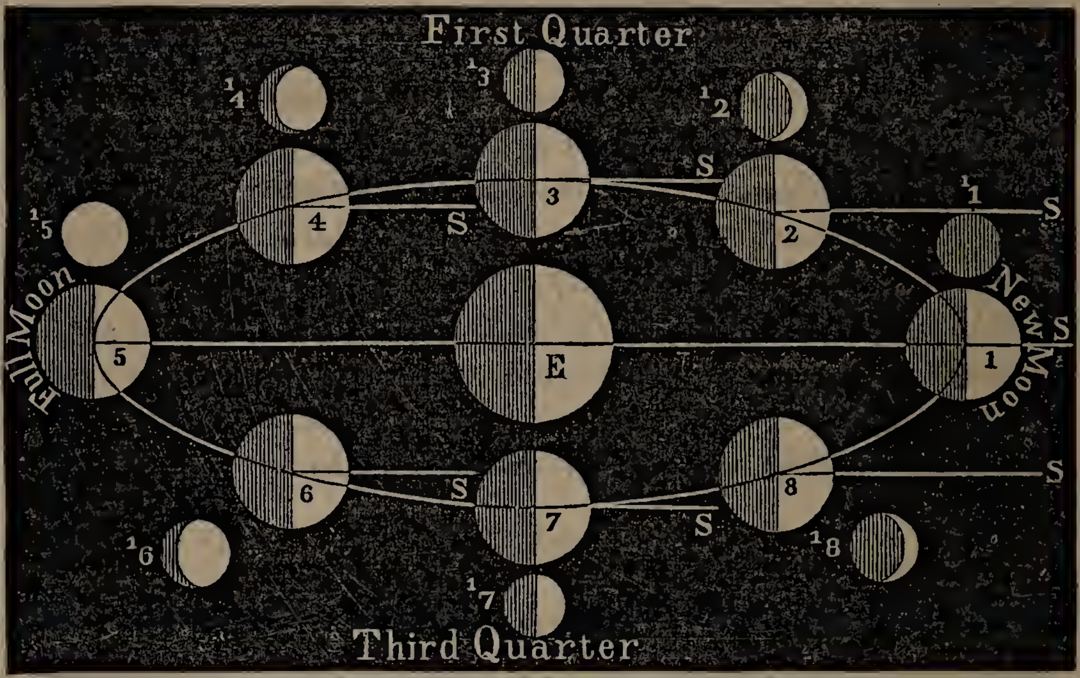
271. After passing her third quarter the moon *resumes* her *crescent shape*, rising *early* in the *morning before the sun.* As her time of rising approaches nearer and nearer to that of the sun, the glittering crescent contracts in breadth, until at length the moon arriving again at CONJUNCTION its light *entirely disappears.* The positions of the moon where she is midway between any two adjacent quarters are termed her *octants.*[3]

1. *Cusps*, from the Latin word *cuspis*, meaning the *point* of a spear.
2. *Gibbous* from the Latin word *gibbus*, meaning *swelled out.*
3. *Octant*, derived from the Latin word *octo*, *eight;* an octant being distant from its *adjacent quarters*, one *eight part* of the moon's *orbit*, or 45°.

From the First Quarter to the Full? From the Full to the Third Quarter? From the Third Quarter to New Moon? What are the octants?

This subject is further illustrated by Fig. 54, where S8, S1, and all lines *parallel* to these indicate the direction in which the sunbeams come, and E represents the

FIG. 54.



MOON'S PHASES.

earth. The *circles* 1, 2, 3, 4, 5, 6, 7 and 8, show the places of the moon in her orbit; at *conjunction* (1,) the *first octant* (2,) the *first quarter* (3,) the *second octant* (4,) at *opposition* (5,) the *third octant* (6,) the *third quarter* (7,) and at the *fourth octant* (8;) while the *white portions* of the circles 1^1, 2^1, 3^1, 4^1, 5^1, 6^1, 7^1 and 8^1, exhibit the *phases* of the moon in all the *preceding positions.* Thus when the moon is at the *first octant* (2,) the *phase corresponding* to this place is displayed in *circle* 2^1, that of the *first quarter* (3,) in circle 3^1; and so of all the other positions.

272. The points in the moon's orbit where she is in *conjunction* and *opposition* are called the *syzygies*[1], and those where she is 90° from the sun the *quadratures.*[2] Fig. 55, exhibits the appearance presented by

1. *Syzygies*, derived from the Greek words, *sŭn*, with and *zeugos*, a yoke, i.e. a *yoking* or *joining together*.

2. *Quadratures*, derived from the Latin word *quadrans*, meaning a *quarter*.

Explain Figure 54. What are the syzygies and the quadratures? What does Figure 55 exhibit.

FIG. 55.

MOON'S QUADRATURE.

the moon in *quadrature* when seen *magnified* through a telescope.

273. WHAT THE PHASES PROVE. The *phases of the moon* clearly prove that this body possesses a *spherical figure*, and is *illumined by the sun;* for it is only a *spherical body*, which viewed in the positions we have mentioned *can exhibit the phases* that the moon has displayed through all past time. This point may be illustrated in the following manner. If in the evening we place a lamp upon a table, and, taking our stand at a distance, cause a person to carry around us a small globe, we shall perceive that the *illumined part of the globe*, in its *circuit* around us, *presents to view* all the phases *of the moon.* Being *crescent shaped* when the globe is *nearly between us and the lamp;* in its *first quarter* when the lines drawn to it from the eye and the lamp make a right angle; and at the *full*, when it is opposite to the lamp: and so on throughout the entire circuit.

274. SIDEREAL MONTH. Upon observing the moon from night to night, we perceive that she has a *motion among the fixed stars;* for if on any particular evening she is beheld *near a star*, on the next succeeding clear evening, she will be seen *far to the east of this star.* And thus the moon continues to advance from *west to east* until, in the space of 27 days 7h. 43m. 11½sec., she makes *one entire revolution*, occupying the same position among the stars as she did at the commencement of this interval. For this reason the period of time just mentioned is denominated a *sidereal month.*

275. SYNODICAL OR LUNAR MONTH. *The time that elapses between two consecutive full moons* or *new moons*, is termed a *synodical*[1] *month*, and consists of 29 days 12h. 44m. 3sec. If the earth was *stationary* while the moon revolved around it, the *length* of the *synodical* month would exactly equal that of the *sidereal*, for the moon in passing *from conjunction*, would then be brought round

1. ***Synodical.*** Derived from two Greek words ***sün***, ***with*** or ***together with***, and ***odos*** a ***journey.*** In union signifying ***a coming together.***

What do the phases prove? Is the moon stationary or in motion? How is she proved to be in motion? In what direction does she move? How long is she in completing a revolution from west to east? What is this period termed, and why? What is meant by a *synodical* or *lunar month?* What is its length?

to *conjunction* again at the *completion of one revolution*. But as it is, while the *moon* is *revolving around the earth*, the *earth* is at the *same time revolving about the* sun in the *same* direction; and the moon in passing from one conjunction to the next, must necessarily describe *more than one complete* revolution. And the same remark is likewise true in respect to any two *consecutive phases*, as for instance from the *third* quarter to the *next third quarter*. In fact in passing from CONJUNCTION to CONJUNCTION, the moon describes not simply 360° *or one entire circumference*, but about 389° 6′, or *nearly one circumference and a twelfth;* and the time which she occupies in going through 389° 6′, is a *synodical month*, or 29 days 12 hours 44 minutes and 3 seconds.

276. This subject may be illustrated, as were the lengths of the *solar* and *sidereal* days (Art. 111,) by the movements of a *watch*. Let us call the *centre* of the *dial plate* the sun, the *end* of the *minute hand* the *moon*, the *end* of the *hour hand* the *earth*, and the 12 *o'clock mark* a *fixed star*. At *twelve o'clock* the *ends* of the *hands* and the centre of the dial are in a *straight line*, or *all together;* the *end* of the *hour hand* (the earth,) is now *between* the *end* of the *minute hand* (the moon) and the *centre* of the *dial* (the sun,) and the *imaginary moon* is in *opposition*. An *hour afterward* the *end* of the *minute hand* (the moon,) is again at the 12 o'clock *mark* which represents the *fixed star*, *and has* made *one complete circuit*, which we can call *a sidereal month*. But it is *not in opposition* for the end of the hour hand which represents the earth is in *advance*, and the opposition will not take place until the *minute hand overtakes* the *hour hand*, when the centre of the dial and the ends of the pointers will be again in the *same straight line;* and this event occurs at 5m. $27\frac{3}{11}$sec. *past* one o'clock. *One hour* in this illustration, therefore, *represents* a *sidereal month*, and *one hour five minutes and twenty-seven three elevenths seconds* a *synodical month*.

Why longer than a *sidereal month?* How many degrees does the moon pass through in the period of a synodical month? Illustrate this subject by the movements of a watch? What length of time in this illustration represents a *sidereal*, what a *synodical month?*

PHYSICAL ASPECTS OF THE MOON.

277. When the moon *is full* we perceive, even with the naked eye, that *her disk* is not *uniformly bright*, but that marked *alternations* of *light* and *shade* extend over the *entire surface.* By the aid of the telescope these peculiarities are more distinctly developed, and *ranges of mountains* are seen and dusky tracts, which the early astronomers regarded *as seas*. These *tracts*, however, are most probably *broad plains* and *precipitous valleys*, for there is strong evidence that but *little moisture* exists in the moon, and close observation moreover shows, that these regions are *too rugged* to be sheets of water.

278. Dr. Dick remarks, "I have inspected these spots hundreds of times, and in *every instance gentle elevations* and *depressions* were seen, similar to the wavings and inequalities which are perceived upon a plain or country generally level." The *surface of a sea or ocean* would present no such appearances.

279. The *proof* that the surface of the moon is *very uneven*, rising into *lofty* mountains, and sinking into *deep valleys*, is quite conclusive. In the first place the *terminator*, which it will be recollected is the *line* that separates the *illumined* part of the disk from the *unillumined*, and is in fact the *profile of the moon's surface*, is *not a regular unbroken line.* Such it would be if the *surface* of the moon was *smooth*, but it is *rough and jagged*, as seen in Fig. 55; thus revealing the existence of *prominences* and *depressions* in the *lunar surface.*

280. Moreover, *near the* terminator *long shadows* fall *opposite to the sun within the illumined regions;* a fact which can only be accounted for by the *uprising of mountains* which *intercept* the rays of this luminary; just as on the earth lofty peaks and pinnacles cast extended *shadows* at the *rising* and *setting* of the *sun.*

281. When the moon is *increasing*, it is *sun rise* at

When the moon is full, what appearances does her disk present to the naked eye? What when seen through a telescope? What views were entertained by the early astronomers? Are these tracts, *seas* or mountains? What does Dr. Dick observe? Would the surface of a sea present the aspects noticed by Dr. Dick? What facts are stated in Arts. 279 and 280, that *prove* the surface of the moon to be rough, rising into mountains and sinking into valleys?

those parts of the illumined region which lie *near the terminator;* and as the terminator *advances beyond* the *mountains* here situated, and the sun *rises higher* and *higher*, the *shadows* of these mountains gradually *shorten.* In the same manner as the mountains of the earth project long shadows at sunrise which *rapidly contract* as the sun ascends the heavens.

282. At *full moon* no *shadows* are seen, for the light from the sun falls *vertically* upon the lunar mountains. If the moon is waning the shadow of any mountain is observed to *lengthen* by degrees as it approaches the *terminator;* being the *longest* when this boundary is reached. When the mountain arrives at the terminator it is there sunset. The shadows of our own mountains undergo the same changes as the day declines.

283. Lastly, *beyond the terminator*, *within* the *unenlightened* parts, *bright spots* or *islands of light* are seen (Fig. 55,) which *must* be the *tops of mountains.* For since *the light of these spots is that of the sun reflected from the moon's surface*, these luminous points catch the solar rays only on account of their being *more elevated than the contiguous regions*, that are veiled in obscurity; and the *farther* these spots are from the *terminator*, the *higher* must the mountains be.

284. If the moon is *increasing*, it is *sunrise* on these *summits* while the dawn prevails below; but if *decreasing* it is *sunset*, while twilight reigns at their base. In the same manner, the peaks of the Alps glow with the first rays of the sun, and around them play the last lingering beams of his rosy light.

285. LUNAR MOUNTAINS. The mountainous regions of the moon present a greater diversity of arrangement than those of the earth. Rugged and precipitous ranges are seen, as on our globe, traversing the lunar surface in all directions; but the moon possesses besides a peculiar mountain formation, termed *ring mountains*, which are detected in every part of her visible surface.

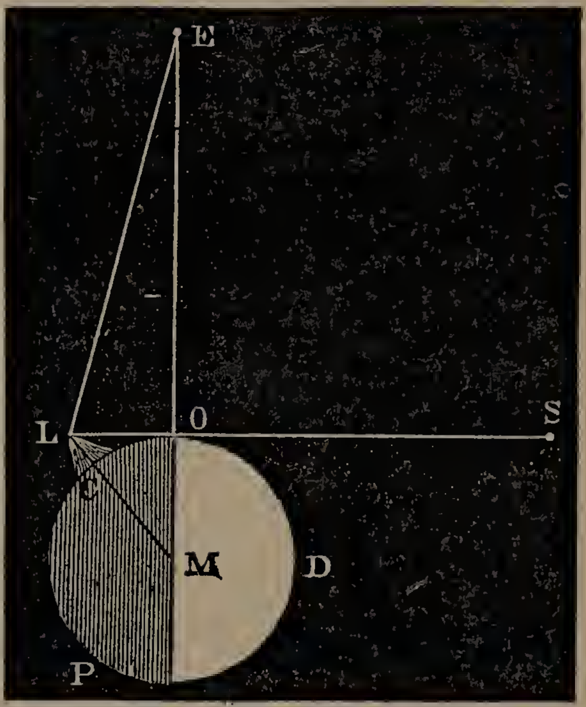
What is said respecting the shadows when the *moon is increasing?* What of them when the moon is *full?* What when *waning?* What fact is adduced in Art. 283, which shows that the surface is rugged? When is it *sunrise* on these summits, and when *sunset?* What is said respecting the mountainous regions of the moon?

A wide plain, and often a deep cavern or *crater*,[1] is beheld encircled by a chain of mountains like a *ring*. These latter in many instances rise to a great altitude; and frequently from the *middle* of the enclosed plain a lofty *insulated peak* shoots far up into the sky.

286. Impossible as it may appear, the *heights* of many of the *lunar mountains* have been calculated, and we shall now proceed to show one of the ways in which the calculations are made.

287. HEIGHT MEASURED. In Fig. 56, let S represent

FIG. 56.



the position of the *sun*, E that of the *earth*, and M the moon in her *first quarter*, the *hemisphere* OD which is turned to the sun being *enlightened*, and the other CP being *dark*. CL is a *lunar mountain*, the *top* of which is *illumined* by the light of the sun, coming in the direction of the ray SOL; and this mountain top consequently appears to a spectator at E, as a *bright spot*, surrounded by the darkness of the unenlightened hemisphere.

288. When the moon is in *quadrature*, as in the figure,

1. *Crater.* Derived from the Greek word *kratĕr*, which signifies a *bowl*.

Have the heights of the lunar monntains been measured? Explain one of the methods employed for estimating the heights?

the line EOM, drawn from E to the centre of the moon, makes a *right angle* with the sun-ray SOL, which touches the *terminator* at O, and strikes the top of the mountain at L.

289. Now an observer at E, sees the top of the mountain in the direction of the line EL, and with the proper instrument he can easily ascertain the magnitude of the angle LEO; which is the *angular distance between* the *summit* of the mountain and the *terminator*. Having obtained this value, and knowing the *apparent diameter* of the moon, and its *length in miles;* the height of the mountain (CL) can be ascertained by means of a property of the *right angled* triangle LOM; viz., that in every right angled triangle the *square of the hypothenuse*[1] *is equal to the sum of the squares of the other two sides.*

290. The calculation is made as follows. Let us suppose that the angle LEO is equal to *one twelfth part* of the *apparent radius* of the moon (15′ 40″;) then will the *line* LO be very nearly equal to *one twelfth* part of the moon's *radius* measured in miles; viz., 90 *miles.* Now the square of LM equals the square of LO (90 × 90,) *added* to the square of OM (1080 × 1080;) that is to 1,174,500. The square root of this quantity, or 1083.74 is therefore, the length of the line LM in miles. LM is then 1083.74 miles long; but it consists of *two parts*, to wit, the *height of the mountain* LC, and the *radius* of the moon CM. Now the length of the latter is 1080 miles, subtracting then 1080 miles (CM) from 1083.74 miles (ML,) the *remainder* 3.74 miles (LC,) is the height of the mountain; *nearly three miles and three quarters.*

291. It is not necessary that the moon should be in quadrature in order to determine, by this method, the height of the lunar mountains, but this phase has been selected because the calculations are *shorter* and less *intricate*, than when the moon is in other positions in her orbit.

A distinguished German astronomer, Schroeter, has

1. The hypothenuse of a triangle is the side *opposite* the right angle.

Show how the calculation is made?

pursued a different method from the one just given. He estimated the altitudes of the moon's mountains, by the *length of the shadows* cast upon its surface.

292. NAMES AND HEIGHTS OF THE LUNAR MOUNTAINS. The method now universally adopted, by the most distinguished astronomers, to designate remarkable regions in the moon, is to assign to these localities the names of men renowned for their attainments in science and literature; as for instance, Newton, Tycho, Kepler, Herschel.

293. The surface of the moon is *more rugged* than that of the earth; for though the former is much smaller than the latter, yet its mountains nearly equal in altitude the *highest* of our own.

294. Prof. Mädler of Prussia, who has studied the physical condition of the moon with more success than any living astronomer, has constructed, in connection with Prof. Beer, another Prussian astronomer of high reputation, large *lunar maps;* in which the most remarkable spots and regions of the moon are laid down with great exactness. Their *magnitudes* have also been ascertained, and their *forms* delineated with the utmost precision.

295. The heights of no less than 1095 lunar mountains have been determined by these astronomers, and out of *twenty* measured by Mädler, *three* tower to an altitude of more than 20,000 feet, while the rest exceed the height of 16,000 feet, or about *three miles.* The names of a few of the loftiest mountains are as follows:

	Feet.		Feet.
Newton,	23,800	Casatus,	20,800
Curtius,	22,200	Posidonius,	19,800.

296. The highest lunar mountain, as we perceive, reaches an altitude of nearly 24,000 feet, or about *four miles and a half;* which is nearly the height of the loftiest mountains of our globe. If our mountains were as

How did Schroeter estimate the heights of the lunar mountains? What method has been adopted in order to designate the remarkable regions in the moon? What is said respecting the surface of the moon? State what has been done by Prof's. Mädler and Beer? How many lunar heights have been determined by these astronomers? What is said respecting the heights of twenty, measured by Mädler? Give the names and altitudes of the *four highest?*

much higher than the lunar as the earth's diameter is *greater* than the moon's, the Himmalehs and Andes would rise to altitude of 16½ miles, above the level of the ocean.

297. LUNAR CRATERS. The moon is not only distinguished for lofty mountains, but also, as we have stated, for singularly formed cavities and craters which are depressed far below the general surface. They are of various sizes, and are scattered all over the disk of the moon; being however most numerous in the southwestern part. In form they are nearly all *circular*, and are shaped like *a bowl;* and from the level bottom of most of the larger a conical hill usually rises at the centre.

298. Oftentimes the *circular walls* of these craters are entirely *below* the general surface of the moon, but they are *usually* elevated somewhat *above* the surface, forming a *ring mountain;* whose height on the *outside* is frequently not more than one-third or one-half of its altitude on the *inside;* measuring from the *bottom* of the *crater* to the top of the mountain.

Twelve craters according to Schroeter are more than *two miles* deep, and to *some* of these a depth of over *four miles* is assigned by the same observer.

299. That these appearances, which are regarded as *cavities* are such in *reality*, is evident from the fact, *that the side nearest the sun is in shadow, while the side most remote is illumined by his beams.* Just as the eastern side of a well is in shadow in the morning, when the sun shines, while the western side at the top is bright with the solar rays.

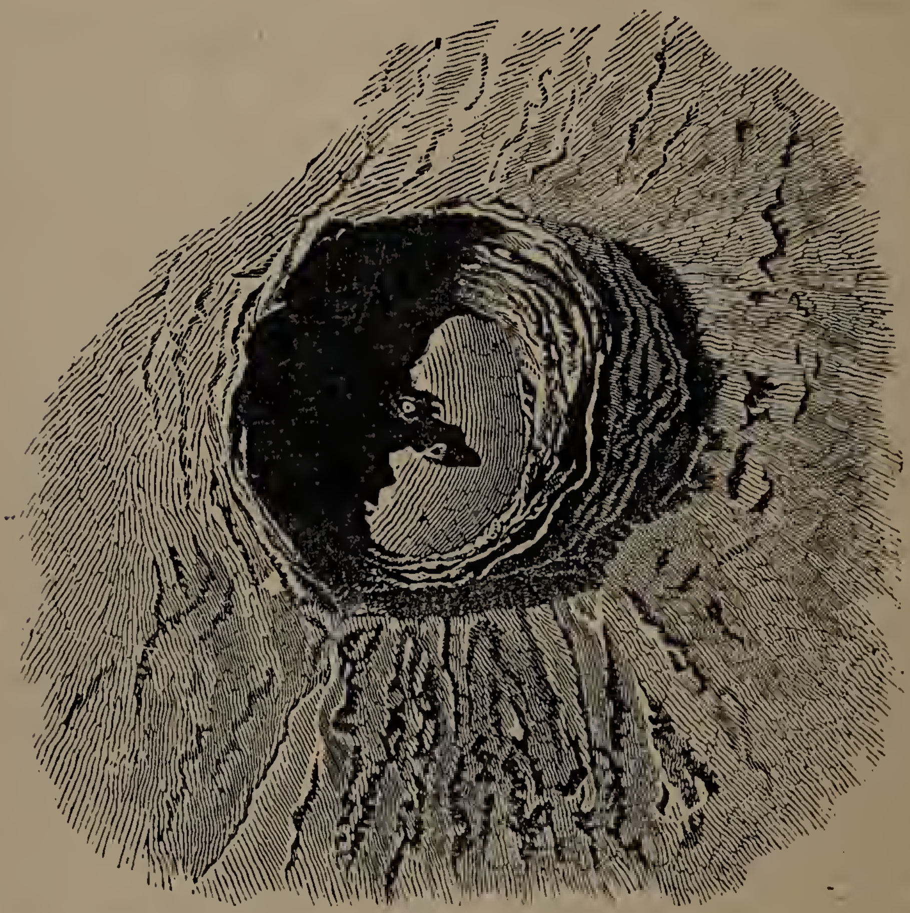
300. One of the finest instances of a ring mountain with its enclosed crater is the spot called Tycho. The breadth of the crater is nearly *fifty miles*, the height of the mountain on the *inside* is about 17,000 feet, and on the outside it is not less than 12,000; the *bottom* of the crater, is therefore 5,000 feet *below* the general surface of the moon.

If the mountains of our globe were as much higher than the lunar mountains as the earth is larger than the moon, how high would the Andes and Himmalehs soar? What is said respecting the lunar craters? Of their sizes and forms? What is said in regard to the circular walls of these craters? How deep are these craters according to Schroeter. State the proofs that these spots are really cavities. Describe Tycho?

From the centre of the enclosed area a beautiful mountain rises to the height of almost one mile.

301. By the aid of a powerful telescope, Tycho is seen as it is delineated in Fig. 57. The ranges of the

FIG 57



A RING MOUNTAIN WITH ITS CRATER, (TYCHO.)

ring mountain are here beheld on the right hand of the figure, with their summits bathed in light, while their sides opposite to the sun, rest in the deepest shade. On the left hand, *nearest to the sun*, the solar rays, streaming over the encircling mountain walls of the crater, leave half of it in darkness; the heavy shadow of the central mountain projecting far into the illumined portion.

302. Many of the craters are of great dimensions, the largest being nearly 150 miles in diameter. The diame-

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Explain the cut. What is said respecting the magnitude of these craters?

ters of the *six* broadest as inferred from the observations of Prof. Mädler, are as follows:

Miles.	Miles.	Miles.
149	143	127
115	113	96

And of 148 craters whose diameters were measured by the same astronomer:

2	were	between	1	and	2	miles	wide
7	"	"	2	"	3	"	"
16	"	"	3	"	4	"	"
19	"	"	4	"	5	"	"
17	"	"	5	"	6	"	"
18	"	"	6	"	7	"	"
11	"	"	7	"	8	"	"
9	"	"	8	"	9	"	"
12	"	"	9	"	10	"	"

And 36 were *above* 10 miles across.

303. Lunar Volcanoes. The existence of *active* volcanoes has been announced more than once by astronomers. In 1787, Sir William Herschel, gave notice to the world that he had observed *three* lunar volcanoes in actual operation, *two* of which were either just ready to break out, or were nearly extinct; while the *third* was in a state of eruption. The burning part of the latter was estimated to be three miles in extent, while the adjacent regions were illumined with the glare of its fires. Since this period the attention of many astronomers has been directed to this subject, and their investigations have led to the conclusion that the remarkable appearances, which were regarded as indicating the existence of volcanoes, can be satisfactorily attributed to other causes, and the opinion is now prevalent among astronomers, that *active* lunar volcanoes *do not now exist.*

304. The aspects of the moon however, indicate that it *has been* the theatre of intense volcanic action, and the *ring mountains* or *craters* strikingly reveal this fact. "In some of the principal craters," says Sir John Herschel,

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Give the diameters of the *six broadest*, according to Mädler's measurements? State what is said of the diameters of 148 craters measured by the same astronomer? What was the belief of Sir William Herschel in respect to the existence of active lunar volcanoes? Have these remarkable appearances been regarded as active volcanoes by later astronomers? What is now the prevalent opinion among astronomers? Are there any indications in the aspects of the moon that active volcanoes once existed?

"decisive marks of volcanic stratification, arising from successive deposits of ejected matter, and evident indications of lava currents streaming outward in all directions, may be clearly traced with powerful telescopes. In Lord Rosse's magnificent reflector, the flat bottom of the crater, called Albategnius, is seen strewed with blocks, while the exterior of another is all marked over with deep gullies radiating toward its centre."

305. LUNAR ATMOSPHERE. On this subject the opinions of astronomers have been much divided. Many have maintained its existence, while others have denied it altogether. Schroeter, the eminent German astronomer, before mentioned, who observed the moon with great care, and under the most favorable circumstances, detected a *faint light* like that of twilight, extending a short distance from the horns of the moon over her dark portions, which are turned away from the sun. This he attributed to the presence of *an atmosphere* rising *about a mile in height* from the surface of the moon. Certain appearances have likewise been observed during eclipses of the sun, when the moon passes between that body and the earth, which are regarded by some as indicating the existence of an atmosphere. If there is an atmosphere it must necessarily be *extremely attenuated*, otherwise it would have given rise to phenomena which must have established, ere this time, the fact of its existence, beyond dispute. In the opinion of Prof. Mädler, who has studied the moon with the greatest assiduity and care, this orb possesses a thin atmospheric envelope of variable extent, and astronomers are now generally disposed to admit, that a *lunar atmosphere exists*; but *so rare*, that if it is constituted like that of the earth it is nearly *two thousand times lighter*. The *pressure* of our atmosphere is counterpoised by a column of mercury 30 inches high; but the pressure of the *lunar* atmosphere would be sustained by a column of mercury about $\frac{1}{66}$th *part of an inch* in altitude, and would be *less*

State the remarks of Sir John Herschel? What are the views of astronomers respecting the existence of a lunar atmosphere? What did Schroeter detect? What other appearances have also been observed? If an atmosphere exists is it *dense* or *rare*? Why rare? What is the opinion of Prof. Mädler, and other astronomers on this subject? What must be the density of the lunar atmosphere compared with the density of our own? How high a column of mercury would support it?

dense that the air remaining in a *receiver*, after exhaustion by an air pump of the best construction.

306. Whenever the moon is seen in an unclouded sky her brightness is always the same, neither speck nor vapor dimming the mild effulgence of her orb. *No clouds* therefore exist in the moon, for a change in its brightness would be detected by us, if masses of vapor swept at times between us and her surface: a perpetual serenity reigns throughout the lunar atmosphere. From this circumstance it is inferred that the moon is *destitute of water;* for if rivers intersected her plains, and lakes and seas spread over her surface, *evaporation* would ensue, and clouds would form and float in the lunar atmosphere. Indeed, the extreme rarity of the moon's atmosphere precludes the supposition of the existence of water. The waters of our globe are kept from wasting away through evaporation by the pressure of our heavy atmosphere; but the lunar atmosphere exerts so slight a pressure, that the waters upon the surface of the moon, if they ever existed, would have speedily been converted into vapor. And if, as some astronomers imagine, the vapors had been removed by some extraneous causes, the moon would ever after possess the characteristics which she now has; namely, *a dry and steril soil and a bright and cloudless atmosphere.*

307. BULK—MASS—DENSITY. The *bulk* of the moon is equal to $\frac{1}{49}$th part of the bulk of the earth, and her *mass* or *quantity of matter* is equal to $\frac{1}{80}$th part of that contained in our globe. The moon's *density* is a little more than *one-half* of the density of the earth.

MOON'S ORBIT.

308. By measuring the diameter of the moon from day to day, astronomers have discovered that the *apparent size* of the lunar disk is subject to variations; the

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What illustration is given to show its extreme rarity? What is said regarding the brightness of the moon? Are clouds found in the moon? What is inferred from their absence? Why? Why is the rarity of the lunar atmosphere incompatible with the existence of water? If it once existed what would have become of it? If the vapors had been removed, what result would have followed? What is the *bulk* of the moon compared with that of the earth? Her *mass*? Her *density*? What is said respecting the *apparent size* of the moon?

greatest apparent diameter of the moon being 33′ 32″, and the *least* 28′ 48″. These changes are evidently due to the circumstance that the moon is nearer to the earth at one time than another; the apparent diameter being *inversely as the distance*, (Art. 177.)

309. Its Figure determined. Taking then the *daily angular velocities* of the moon in her orbit, and her *daily variations* in *apparent size*, we can determine the *figure* of her orbit in the same way as we ascertained that of the earth, (Art. 178.) By mapping down the differing *lengths* of the *radius vectors* and their *angular distances* from each other, we find the orbit of the moon to be an *ellipse*, with the earth in one of the foci. The orbit of the moon *deviates* more from a *circle* than that of the earth.

310. The changes in the moon's apparent size prove, that when she is *nearest* to the earth, or at her *perigee*, her distance may be as small as 225,560 miles; while at her most remote point from the earth, or her *apogee*, her distance may increase to 251,700 miles. So that the *variation* in the moon's distance from us amounts to 26,000 miles; an extent of space exceeding the circum ference of the earth.

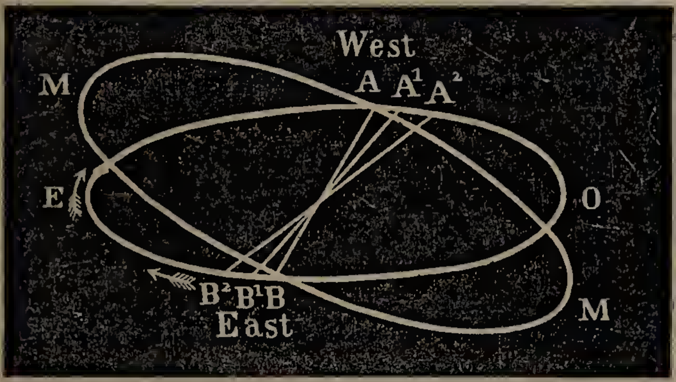
311. The same results are obtained from the *changes* that take place in the *horizontal parallax* of the moon, these changes being also *inversely as the distances*, (Art. 95.) The *greatest* horizontal parallax, according to Biot, is 61′ 29″ and the *least* 53′ 51″, while the *mean* parallax is 57′ 4″.

312. Plane of the Moon's Orbit—Its Inclination. The plane of the moon's orbit, is inclined to that of the earth's (the *ecliptic*) at an angle of about 5° 8′. This inclination is not always the same, being sometimes greater and sometimes smaller than this quantity. The variation is however trifling, never exceeding 23″.

What is the *greatest* apparent diameter? What is the *least?* Explain the cause of hese variations? How is the figure of the moon's orbit determined? What is its figure? How does it compare with the orbit of the earth in respect to its *ellipticity?* What is the distance of the moon from the earth at her *perigee*, as proved by the changes in her apparent size? What at her *apogee?* How much does the *variation* in distance amount to? In what other way are these results obtained? What is the *greatest horizontal parallax* of the moon, according to Biot? What the *least?* What the mean? What is the *inclination* of the *plane* of the *moon's orbit* to that of the *ecliptic?* Is this inclination always the same? What is the extent of the variation?

313. THE LINE OF THE NODES. The moon in making one revolution about the earth comes *twice* into the plane of the earth's orbit. These *two positions*, when the centre of the moon is at the *same time* in the plane of the ecliptic, and in that of her own orbit, are called the *moon's* NODES.[1] A line joining these two points, is in *both* these planes, and is termed the *line of the nodes.* In Fig. 58, EO represents a part of the plane of the *earth's orbit*, MM the *moon's orbit*, A and B the *moon's nodes*, and AB the *line of the nodes.*

FIG. 58



LINE OF THE NODES.

314. The centre of the moon, at each revolution about the earth, meets the ecliptic in a *different* place from that in which it met it at the *preceding* revolution. Thus if on the 15th day of June, the node was at A, Fig. 58, at the end of the next revolution the centre of the moon would be in the plane of the ecliptic, to the *west* of its former place, and the node would be at A^1. In the succeeding revolution it would be at A^2, and so on. In like manner the other node would shift along from B to B^1, B^2, &c., and the *line of the nodes* would take the successive positions AB, A^1B^1, A^2B^2, and so on. The line of the nodes thus *appears* to revolve from *east to west*, and this phenomenon is called the *retrogression* or *going back of the nodes;* because they shift in a direction contrary to that in which the heavenly bodies generally move.

1. From the Latin word **nodus**, meaning a **knot**, a **connection.**

What is meant by the moon's nodes? What by the line of the nodes? Explain the figure. Are the nodes fixed in space? Explain from figure. In what direction does the line of the nodes appear to revolve? What is this phenomenon termed?

315. The line of the nodes retrogrades about 3′ 10″ *daily*, and in the course of 18 years 218d. 21h. 22m. 46sec., it makes the *entire circuit* of the ecliptic; so that, at the termination of this period of time, it occupies exactly the same position in space as it did at the beginning.

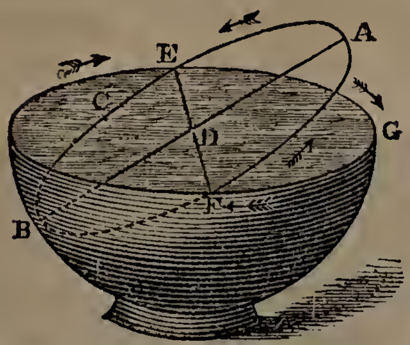
316. LINE OF THE APSIDES. If, when the moon is at her *perigee* and *apogee*, we were to measure the angular distances of these *points* from either of the moon's *nodes*, and continue to do so for several *successive revolutions*, we should find that these distances constantly *varied*. The places of the perigee and apogee shifting along the lunar orbit from *west to east*, and the imaginary line joining these two points, called the *line of the apsides*, necessarily revolving in the same direction.

317. This motion is so rapid that the line of the apsides completes an *entire revolution* in 8 years 310d. 13h. 48m. 53sec., so that the perigee occupies the place in the lunar orbit that the apogee did about 4 years 155 days before; and returns to the place in the lunar orbit whence it started, at the end of the longer period just mentioned.

318. The *motion* of the *line of the nodes*, and that of the *line of the apsides* may be illustrated as follows: Let us first take a round bowl, Fig. 59, and fill it with water to the brim, and in the next place an elliptical ring ABC, which we place in the bowl, inclined to the surface of the water at an angle of about 5°. This ring may represent the *moon's orbit*, A her *perigee*, the *surface* of the water the *plane* of the *ecliptic*, and E, F the intersecting points of the orbit of the moon with the ecliptic, namely *the nodes*; EDF is the *line of the nodes*, and ADB the *line of the apsides*. Now if we make the ring to *revolve on its centre* D in the direction *from* A towards E, always preserving the *same inclination* to the surface of the water; while at the same time it is made to *slide round on the edge of the bowl* in the *contrary direction* EGF, at

What is the *daily amount* of retrogradation? In what period does the line of the node make a complete revolution? Are the moon's *perigee* and *apogee stationary* as respects her *nodes*? In what direction do they move? What is the line of the apsides, and how does it move? In what period would this line make a complete circuit? Explain by the aid of Figure 59, the motion of the line of the nodes and of the apsides.

FIG. 59.



MOTIONS OF THE NODES AND APSIDES.

about *half the rate* at which it revolves on its centre, we can roughly represent both the motion of the line of *the nodes*, and that of the line of the *apsides*. For it is evident, *first*, that the supposed line of the nodes EDF, would revolve in the imaginary plane of the ecliptic, crossing it in all directions; and *secondly*, that the line of the apsides ADB would also revolve in any opposite direction in the plane of the lunar orbit, cutting the line of the nodes at all angles, being at one time *perpendicular* to it, and at another *coincident* with it. All which motions and changes in position, are in accordance with the lunar phenomena just described.

319. INCREASED APPARENT SIZE OF THE MOON WHEN IN THE ZENITH. When the moon is in the *zenith* she is *nearer* to us than when upon the *horizon*.

This fact is evident from the inspection of Fig. 60, where HOZD, is a portion of the moon's daily path, M her position in the *zenith* to a spectator on the earth at P, and M[1] her position on the *horizon;* the line HH[1] being in the plane of the horizon.

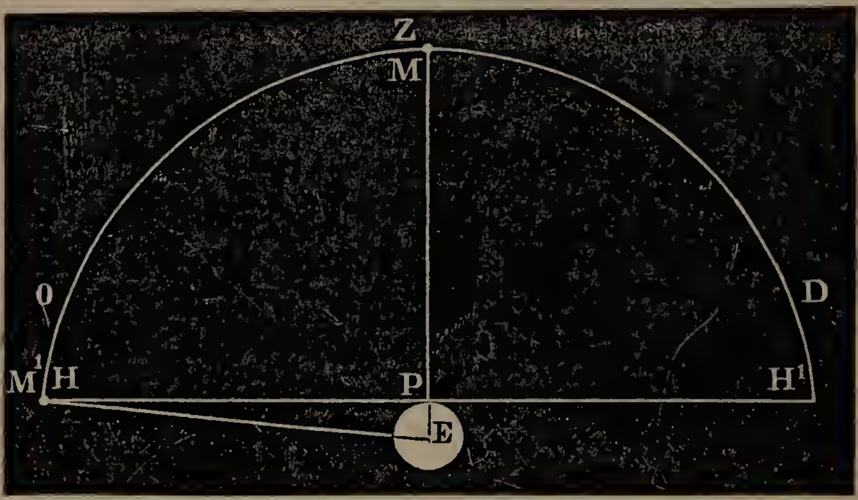
Now calling E the centre of the earth, EM, the distance of the moon when in the zenith, is equal to EM[1], her distance from the *centre* of the earth when on the horizon; and EM[1] is very nearly equal[1] to PM[1], which is the distance of the moon on the horizon from a spectator on the surface of the earth at P. PM[1] is there-

1. The *difference* in the *distances* PM[1] and EM[1] is only about *thirty miles*.

Does it make any difference in the distance of the moon from us whether she is in the zenith or upon the horizon? In which position is she *nearest* to us? Prove it from Fig. 60

fore nearly equal to EM, but PM, the distance of the moon in the zenith from the spectator at P, is *shorter*

FIG. 60



MOON'S APPARENT SIZE INCREASED IN THE ZENITH.

than EM by PE, the radius of the earth, and is therefore *less* than PM^1 by about the same quantity.

320. The moon is therefore *nearer* the spectator when she is in the *zenith* than when she is upon the *horizon* by almost 4,000 miles. This change in distance of course affects her *apparent size*, and it is found by measurement that the breadth of the moon is $\frac{1}{60}$th part *greater* at the *zenith* than at the *horizon*, a result which verifies the preceding demonstration. For since the moon's distance is *inversely* as her *apparent diameter* she ought when in the zenith, to be $\frac{1}{60}$th of her distance *nearer* the earth than when upon the horizon. Now since her average distance from the earth is about 240,000 miles, $\frac{1}{60}$th of her distance is 4,000 miles, which is the length of the radius of the earth in round numbers, and is nearly equal to the difference of the distances PM and PM^1.

321. THE MOON ALWAYS TURNS THE SAME FACE TOWARDS THE EARTH. Every observer whose attention has been drawn to the fact, has noticed that the appearance of one full moon is *almost* exactly like that of another. There is the *same relative arrangement* of light

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By how much is she then nearer to us? Does this change in distance affect her apparent size? How much greater is her apparent size when she is at the zenith than when she is upon the horizon? What does this verify? Show in what way?

and shade, and the most remarkable features, such as prominent mountains and valleys, are constantly seen in nearly the *same positions* on the moon's disk. This is indeed true in respect to *all the lunar phases;* for the surface of the moon as seen at her first quarter, is that which has been seen at every first quarter since the creation, and the same which will be seen at the same phase, as long as the sun, moon, and earth endure.

322. This singular phenomenon can be explained only on the supposition, that the *moon rotates on her axis in about the same time that she completes a sidereal revolution around the earth;* for if she did not thus rotate we should see the greater part of her surface in the course of a month; which is not the case.

323. This point may be thus illustrated. We will suppose a person standing in the middle of a floor, and another walking around him in a circle, holding up at a level with his eye, *a globe,* of which the surface of *one hemisphere* is painted *black,* and that of the *other white.* The first person represents a spectator upon the earth, the circle in which the second walks the orbit of the moon, the globe is the *moon,* and the *white surface* the *side* that she constantly presents towards the earth. Now it is manifest, that if the second person walking round the circle wishes the spectator at the centre to see *nothing but the white surface of the globe,* as he performs his circuit, he must turn the globe round on its vertical axis, at *exactly the same angular rate* that he himself is moving in the circle. Thus when he has moved through one quarter of the circle, the globe must have turned *one quarter* of a circle, when he has traversed *one half* of the circle, the globe must have turned *half round;* and so on through the entire circle.

324. Libration in Longitude. If the person holding the globe does not always walk at *the same pace,* but sometimes moves at a *slower,* and sometimes at a *faster rate* than the *uniform speed* at which the globe *rotates* on its axis, the spectator at the centre will see a *little* of the

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How does the appearance of the moon at any phase during any one month, compare with her appearance at the *same phase,* during any *other month?* How can this phenomenon be explained? Give the illustration?

dark hemisphere, first on this side, and then on that; and thus a *little more than a hemisphere* will fall *into view* in the course of *a revolution.*

325. Now a similar phenomenon occurs in respect to the moon, inasmuch as she moves *uniformly* on her *axis*, but *not so* in her orbit; and therefore we can see at times *beyond* the average boundaries of the moon's disk, to the extent of a few degrees of surface on the *east* and *west* sides.

At one period a spot, which was visible a little before on the *eastern side*, *disappears*, while others are seen on the *western side*, which were not previously discerned. Ere long the *latter* pass beyond the illuminated hemisphere, and vanish; while the *former* reappear on the bright surface.

326. This apparent motion is called the LIBRATION[1] OF THE MOON IN LONGITUDE, because she undergoes a change in position as if, while *balancing* upon her axis, she swung *backwards* and *forwards* from *east to west* and from *west to east;* in which direction, *longitude is reckoned* on the earth.

327. LIBRATION IN LATITUDE. The axis about which the moon rotates, though always maintaining the same direction in space, is *not quite perpendicular to the plane of her orbit*, but is inclined to it at an angle of about $88\frac{1}{2}°$ ($88° 27' 51''$.) Consequently, in certain positions in her orbit, we see a little space *beyond one of* the lunar poles and a little distance *short* of the *other;* each pole *appearing* and *disappearing* in its turn. Just as a spectator upon the *sun*, at the time of the northern summer solstice, could look about $23\frac{1}{2}°$ *beyond* the *north* pole of the earth, while all the region within the *same distance* of the *south pole* would then be lost to his view: the *reverse* occurring at the northern winter solstice, *all the southern frigid zone* then coming into sight and the *northern disappearing* (see Fig. 40.) A small space therefore

1. ***Libration***, from the Latin word ***libratio***, meaning a ***poising*** or ***balancing***.

Explain libration in *longitude?* Why is this motion so termed? What is the inclination of the moon's axis to the plane of her orbit? What phenomenon is caused by this inclination? Give the illustration?

around each of the poles of the moon is concealed from view or presented to our sight, according as this luminary is in one or another part of her orbit.

328. This phenomenon is termed *libration in latitude*,[1] because the change in the visible surface takes place in a direction *from* the moon's equator, and terrestrial latitude is reckoned in this manner.

329. DIURNAL LIBRATION. It is towards the *centre of the earth* that the moon presents the *same face*, and she would at all times do so to a spectator situated in the line joining the centres of the earth and moon, if the librations of longitude and latitude did not exist. But it is only when the moon is on the *meridian* that we are nearly in the line of the centres. When she is upon the *eastern horizon* we, standing upon the earth's *surface*, are elevated nearly 4,000 miles *above* this line, and *overlook* portions of the lunar surface, which are invisible when the moon is on the meridian.

330. And the same is true when she is upon the *western horizon*, only the change then occurs on the *opposite side* of the lunar orb; since the *upper* side of the moon at her *rising*, is the *lower* at her setting. These variations in the aspect of the moon happen daily, and the phenomenon is termed the *diurnal libration*. At the moon's *rising* and *setting* the diurnal libration is greatest, since the spectator can not attain any higher elevation above the imaginary line uniting the centres of the earth and moon, than when the latter is upon the horizon.

331. LENGTH OF THE LUNAR DAY. The moon, as we have seen, rotates on her axis in the *same period* that she completes a *sidereal* revolution about the earth, moving forward in the meanwhile with the latter around the sun, through an arc of nearly 27°. Owing to these *two* motions the average length of the day *at the moon*, reckoning by *solar time*, is equal to the length of a *synodical* month, that is to about 29½ of our days (29 days

1. These *variations* in the moon's *visible* surface seem to arise as if her *axis vibrated to* and *from* the earth.

What is this phenomenon called, and why? Explain what is meant by diurnal libration? When is it greatest? What is the mean length of the lunar day measured by our days?

12h. 44m. 2.9sec.) The mean lengths of *daylight* and *night* are therefore respectively equal to nearly 15 of our entire days of 24 hours duration.

332. At the *lunar equator* the days and nights are of *equal length*, each being about 354 hours and 22 minutes long, (14d. 18h. 22m. 1.5sec.,) but they vary with the latitude. Thus at the *lunar* latitude of 45° the extent of the *longest* day[1] is 354h. 19m., and that of the *shortest* 351h. 26m.; while at latitude 88°, the *longest* day has a duration of 449h. 28m., and the *shortest* of 259h. 16m.

333. THE APPEARANCE OF THE EARTH AS SEEN FROM THE MOON. To the inhabitants of the moon (if any there are,) our earth is seen as a *moon of immense size*, its *apparent surface* being *sixteen times* greater than that of the sun as he appears to us. For this reason a vast amount of light must be reflected from our globe to the moon, and all the varied lunar phases which we behold would be exhibited by the earth to a lunar spectator with a wonderful radiance and distinctness, but in an *inverse* order. Thus when it is *new moon* to *us* it would be *full earth* to an observer on the moon, and when *full moon here*, *new earth there*.

334. Another remarkable difference also exists. The moon is seen by us occupying various positions in the heavens, as she displays her successive phases; but the earth would appear to an inhabitant of the moon to be *fixed in the heavens*, during *all* her periodical fluctuations of light. The cause of this singular phenomenon is easily explained. The moon turns on her axis from *west to east* just as the earth does, but an inhabitant of the moon would be as *unconscious* of its *rotation*, as we are of the rotation of the earth. Accordingly, as with us, the sun and the other *fixed* heavenly bodies would appear to him to be moving from *east to west*, at *the same rate* that his own orb rotates on its axis. Such would be the apparent motion of the earth to a specta-

1. The word *day* is here used in distinction from *night*.

What the respective lengths of *day* and *night* at the lunar equator? What the duration of the longest and shortest days at the lunar latitude of 45°? What at 88°? How would our earth appear to an inhabitant of the moon? In what order would the phases of the earth be exhibited?

tor upon the moon, if *the earth was actually stationary;* but this is not the case, for our globe advances from *west to east* in her orbit, *just as rapidly* as the rotation of the moon *tends* to give it an *apparent retrograde* motion from east to west.[1] The earth, therefore, *apparently* moving in *one direction* exactly as fast as it *actually* moves in the *opposite* direction, consequently seems to an inhabitant of the moon to *stand still*[2] in the heavens.

335. These phenomena would only be seen by a spectator on the side of the moon *nearest* to us, for to those inhabiting the remote hemisphere the earth would *never* come into *view.* Their long nights of nearly 15 days duration would therefore be extremely dark, since the brightest heavenly bodies, whose light could dissipate the gloom, are Mars and Jupiter, which would afford no more illumination to the inhabitants of the moon than they do to us.

336. ACCELERATION OF THE MOON'S MOTION IN HER ORBIT. The time occupied by the moon in revolving about the earth is *now* really *less* than it was centuries ago. This remarkable fact was discovered by Dr. Halley, in the following manner. Knowing the periodic time of the moon, as computed from the observations of modern astronomers, he compared it with that, deduced from the Chaldean observations of eclipses at Babylon, in the years 719 and 720, before Christ; and also with the periodic time obtained from observations made at Cairo, by Ebn Junis, an Arabian astronomer who flourished in the 10th century.

1. The moon would present the same phenomenon to us if she completed a revolution in her orbit in a *sidereal day*, for she would then *actually* move as fast from *west to east* as she would *apparently move* from *east to west* on account of the rotation of the earth. Under these circumstances, she would seem *not to move at all.*

2. Though the earth would have no *progressive* motion in the heavens, she would change her place a little on account of her *librations*, *rocking to and fro* to a small extent in a direction *parallel* to her *equator* (*libration in longitude*,) and also in a direction *perpendicular* to it (*libration in latitude.*)

Would the earth have any *apparent* motion as seen from the moon? Give the explanation? Could these phenomena be seen from every point of the moon's surface? Why not? What is said respecting the nights that prevail throughout that hemisphere of the moon which is turned from us? What is said in respect to the time *now* occupied by the moon in revolving about the earth?

337. These comparisons showed, that the motion of the moon had been *accelerated* from the era of the Chaldean observations to that of Ebn Junis, and also from his time to that of Dr. Halley.

The investigations of the profound mathematician La Place, have proved the existence of this phenomenon beyond a doubt.

The amount of this acceleration of the moon's motion is extremely small being only a little more than *ten seconds* (10″) in every *hundred years.*

338. This variation in the moon's velocity, was at first accounted for, by supposing that the space through which she moved was filled with a fluid like air, which, by the resistance, it opposed to the mass of the moon, *lessened* her *centrifugal force.* The earth would consequently draw the moon closer to herself, thus *diminishing* the magnitude of her orbit and decreasing her periodic time.[1]

339. La Place, however, showed that this view was erroneous, and proved that this increase of motion[2] was caused by a gradual diminution in the *eccentricity* of the earth's orbit. Moreover, that this diminution will continue for ages, when it will cease, and then the eccentricity will begin in turn to increase; and that these alternate changes will continue while the solar system exists. The acceleration of the moon must therefore follow the same law. For ages the motion will grow *swifter* and *swifter* until the eccentricity of the earth's orbit begins to *increase;* after that era the moon's motion will be gradually slower and slower; until again, at the end of countless ages, the limit will be reached, and her speed once more accelerated.

340. The Moon's path in space. Since the moon revolves about the *earth*, and at the same time about the

1. The *periodic time* of the moon is the time occupied by this orb, in completing a revolution about the earth.

2. The periodic time being *decreased*, the motion of the moon must be *increased.*

Who discovered this fact? In what manner? Whose investigations clearly proved its existence? What is the rate of the acceleration? How was this phenomenon at first accounted for? What did La Place prove?

sun,[1] moving along with the earth in its annual circuit, her path in space necessarily partakes of these two motions. Being now inside of the earth's orbit, and now outside, the path she describes around the sun and earth is an epicycloidal curve, intersecting the orbit of the earth twice every lunar month, and every where concave towards the sun. The whole departure of the moon from the earth's orbit either way does not exceed *one four hundredth* part of the radius. Her path therefore around the sun, does not sensibly deviate from the elliptical orbit of the earth.

341. The moon in her motions is subject to numerous irregularities, the explanation of which has tasked the highest powers of the most gifted astronomers.

CHAPTER III.

ECLIPSES OF THE SUN AND MOON.

342. THE *eclipses* of the sun and moon are among the most grand and sublime of the phenomena of the heavens. In all ages of the world, they have been viewed by the ignorant with wonder and awe; while to the man of science they have ever been subjects of deep interest and profound study.

LUNAR ECLIPSES.

343. *An eclipse of the moon is the partial or total obscuration of her light, when she passes into the shadow of the earth.* The sun, earth, and moon, are then in nearly the same straight line with the earth *between* the other two bodies If the moon were *self-luminous*, like the sun, a

1. The moon is not *borne along* by the earth, around the sun, she would revolve about the latter, if the earth was *annihilated*.

State what is said respecting the moon's path in space? What in regard to her motions? Of what does Chapter III. treat? What is said respecting the eclipses of the sun and moon? What is an eclipse of the moon? When it occurs, what are the relative positions of the sun, moon, and earth?

lunar eclipse could *never occur;* but shining as she does by reflection from the sun, the interposition of the solid body of the earth, cuts off the solar light, and the portions of the moon that enter the earth's shadow appear *dark* to our view. A lunar eclipse can never happen except when the moon is *full*, for it is only at this time that the earth is *between* the sun and moon, and its shadow is extended in the direction of the *latter*.

344. If the plane of the moon's orbit coincided exactly with the plane of the ecliptic, she would pass through the earth's shadow at every revolution, and a lunar eclipse would take place at *every full moon*. But as the former is inclined to the latter at an angle of about 5° (Art. 312,) the *shadow* of the earth may at one time *pass above* the *full moon*, and at another *below* it. The full moon must therefore take place within a certain distance of one of her *nodes*,[1] that is, *near the plane of the ecliptic*, to make it *possible* for an eclipse[2] to occur.

345. When the moon, at the full, has her centre exactly at her node, it is in the *same straight line* with the centres of the sun and earth, and she is placed centrally in the shadow of the earth. But it is not necessary that the moon should be precisely in this position in order that an eclipse may happen; for since she possesses an apparent breadth of about 30′, and the shadow of the earth extends on each side of the node, her disk may be obscured when she is within a short distance of this point.

The calculations of astronomers accordingly show that an eclipse *may* happen when the moon at the full is not *more* than 12° 24′ distant from one of her nodes, and *must* happen if her distance does not exceed 9°.

1. It will be remembered that the moon's *nodes* are those points in her orbit where the latter *intersects* with the plane of the ecliptic. They are consequently at once in the plane of the moon's orbit, and in that of the earth's.

2. *Eclipses* are so called from the Greek word εκλειψισ meaning a "disappearance."

If the moon was self-luminous would there be any lunar eclipses? In what phase must the moon be when a lunar eclipse happens? If the plane of the ecliptic and that of the moon's orbit coincided, how often would lunar eclipses occur? Why do they not now take place every month? Near what point must the full moon be to make it possible for an eclipse to happen? Explain why it is not necessary for the moon to be exactly at one of her nodes for this phenomenon to occur? State the limits within which a lunar eclipse *may* happen? Those within which it *must* happen?

346. When the moon is *entirely* obscured, the eclipse is called *total;* when only a *portion* of the disk is concealed *partial*, and when the disk just touches the *edge* of the shadow, the phenomenon is termed an *appulse.*

347. OF THE EARTH'S SHADOW. Since the rays of light move in straight lines, the shadow of a globe illumined by one of greater size is *conical*, and the length of its shadow will depend upon the *size* and *distance* of the illuminating body. For the *greater* the relative *size* and the *less* the *distance* the *shorter* will be the shadow, and the *smaller* the *size* and the *greater* the *distance* the *longer* the shadow. The sun being vastly greater in magnitude than the earth, the shadow of the latter is accordingly conical.[1] (Fig. 61,) and though they never vary in size, yet as they vary in their distances from each other, the earth's shadow is *changeable* in length, being *shortest* when the sun is in *perigee* and *longest* when in *apogee.*

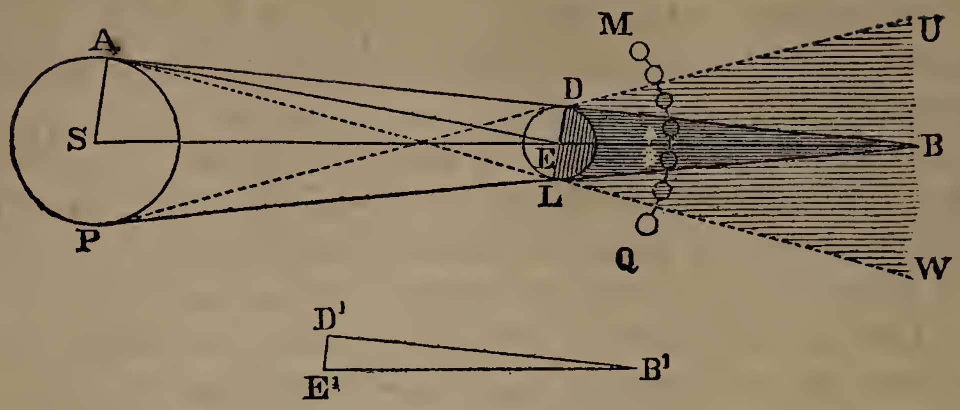
348. It is by no means a difficult matter to determine the *length* of the shadow, and by the aid of Fig. 61, we will explain the manner in which the calculation is made. In this figure S represents the centre of the sun, E that of the earth, and AD and PL rays of light from the edges of the sun, touching the earth at D and L, and meeting at B. The lines BD and LB bound the shadow, SEB is a straight line drawn from the centre of the sun through that of the earth, to the extremity of the shadow, and EB is the length of the shadow. Our task is to find *how many miles* long EB is.

349. We must first direct our attention to the triangle DEB. We know the extent of DE, for it is a *radius* of the earth, and is 3956.2 miles long; moreover, EDB is a right angle; for if a line (as ADB) touches the surface of a sphere at any point, and a line (as DE) is

1. Strictly speaking the shadow is not an *exact cone*, the base of which is a circle. It would be a cone if the earth was a perfect sphere but being an ellipsoid the base of the shadow is an ellipse instead of a circle.

When is an eclipse *total?* When *partial?* What is an *appulse?* What is the form of the shadow of a globe illumined by one of a greater size? What does the *length* of the shadow depend upon? What is the form of the shadow of the earth? When longest? When shortest? Can its length be calculated?

FIG. 61.



drawn from the centre of the sphere to that point, the line drawn from the centre and the touching line always make a *right angle* with *each other.* Now join AE, and we thus form two angles; viz., DAE which is the *sun's horizontal parallax*, (Art. 94,) and AES which is the *sun's apparent semi-diameter*. In geometrical language AES, is called the *exterior* angle of the triangle AEB, and is equal to the *sum* of the two angles ABE and BAE. The angle EBA, is therefore equal to the angle AES, *diminished* by the angle EAB; or in other words equals the *difference* between the sun's *apparent semi-diameter* and his *horizontal parallax*. The value of the *difference* at the sun's mean distance is 15′ 51.4″. Therefore, in the triangle DEB, since we know the value of all the angles and the length of one side, we proceed to select from the trigonometrical tables a similar triangle as $D^1E^1B^1$, and institute a proportion as we have before shown between the sides.

350. We thus find, that if the line B^1E^1 represents *one mile*, D^1E^1 consists of *four thousand six hundred and twelve millionths of a mile;* and the proportion runs thus, D^1E^1 (,004612ths of a mile) : B^1E^1 (one mile) : : DE (3956.2 miles) : BE. *Multiplying* together the second and third terms of the proportion and *dividing* by the first, we obtain for the value of BE 857,806 miles. The mean or average length of the shadow is therefore about 860,000 miles, extending beyond the earth's centre to a distance more than *three and a half times* that of the

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Explain how by Fig. 61. What is the *mean* length of the earth's shadow in miles?

moon from the earth. When the sun is at the *perigee*, the length of the shadow is about 14,400 miles *shorter*, and when at the *apogee*, nearly 14,700 miles *longer* than the mean value.

351. EXTENT OF SHADOW TRAVERSED BY THE MOON. It is proved by mathematical investigations, that the average breadth of the earth's shadow where the moon crosses it, is about *three times the diameter of the moon* or nearly 6,500 miles. But the length of the moon's path through the shadow is affected by *two circumstances; First*, the varying distance of the sun from the earth; *Secondly*, the varying distance of the moon from the earth. For when the sun is in *apogee* at the time of the eclipse, the *breadth* of the shadow, at the average distance where the moon crosses it, will be *greater than usual;* (Art. 350,) and if the moon then happens to be in *perigee*, she will cross the shadow about 13,000 miles *nearer the earth* than at her average distance of 240,000 miles, and will consequently traverse a *broader part* of the shadow.[1]

But if the *reverse* happens, the sun being in *perigee*, and the moon in *apogee*, the proximity of the sun will *narrow* the earth's shadow at the average distance where the moon crosses it, while the moon being now *farthest* from the earth, will pass through the shadow at a *still narrower* place, nearly 13,000 miles, *beyond* its average place of crossing.

352. OF THE PENUMBRA. On each side of the shadow of the earth there exists, to a certain limit, a space where there is a *partial shadow* or *penumbra.*[2] Outside of this space the moon is illumined by the full orb of the sun, but as she enters the *penumbra* the dark body of the earth begins to interpose itself, and cuts off *a portion* of the sun's light. As she continues to ap-

1. It will be remembered that the moon in *apogee* is 26,000 miles farther from the earth than when in *perigee* (Art. 310.) Her *average* distance will therefore differ from her apogee and perigee distances by 13,000 miles.

2. See page 133, note 2.

How does it compare in length with the moon's distance from the earth? When the sun is in perigee, how much shorter is the shadow than its mean length? When the sun is in apogee how much longer? What is the average breadth of the earth's shadow where the moon crosses it? By what *two* circumstances is the length of the moon's path through the shadow affected? Explain why? What is the penumbra?

proach the shadow, more and more light is intercepted, and at the moment the earth *totally* hides the sun from any part of the moon, that part at the same instant passes the *inner limit* of the penumbra and *enters* the shadow.

353. The space occupied by the penumbra is determined as follows: Referring to Fig. 61, and supposing the lines ALW and PDU, to be drawn, touching the earth at the points D and L,[1] the penumbra is found on each side of the shadow bounded by the lines UD, DB and BL, LW. QM represents the *path* of the moon, and the several small circles on the line QM, are different *positions* of the moon *at* and *near* the time of an eclipse.

354. It is evident from the slightest glance, that the moon when nearest Q, is exposed to *all* the light of the solar disk; but that as soon as she passes *beyond* the line LW, a portion of the sun *near* A, *can not* be seen from the moon, on account of the interposition of a portion of the earth at L. More and more of the sun's disk will become invisible at the moon as she advances towards the line LB, and when she has passed this line, the disk of the sun is *entirely concealed* from a *part* of her surface, if not from *all*, by the intervention of the earth.

355. The moon leaves the shadow, re-entering the penumbra on the *opposite side*, when she has crossed the line DB; for here rays of solar light from the regions about A now shine upon her, and when she has passed the line DU, she emerges from all obscurity and the full light of the sun again illumines her surface. The space DBL therefore comprises the *shadow* of the earth, while the *penumbra* is limited as before stated, by the lines UD, DB and BL, LW.

356. DURATION OF A LUNAR ECLIPSE. When a *total eclipse* occurs, the moon, if she passes *centrally* through the shadow, may be completely obscured for the space

1. The straight lines PU and AW do not touch the surface of the earth at *exactly* the *same points* where AB and PB touch; viz., at D and L, but *very near* them.

State what changes in illumination the moon undergoes, as she advances from beyond the penumbra into the shadow? Explain from figure. For what space of time is the moon obscured during a total eclipse, when she passes centrally through the shadow?

of about *two hours*, for she moves through a space equal to her own breadth in about *an hour*, and as the breadth of the earth's shadow where the moon crosses it is nearly *three times her diameter*, she must traverse *two thirds* of the breadth of the shadow in obscurity.

357. The duration however of *complete eclipse* will depend upon the *direction* of the moon's transit through the shadow, and also upon the *varying distances* of the *sun* and *moon* from the earth, as explained in Art. 351. A lunar eclipse may continue for the space of about *five and a half hours*, counting from the moment the moon enters the penumbra, till the instant she leaves it.

358. RED LIGHT OF THE DISK. During a *lunar eclipse* the darkened surface of the moon is illumined by a *reddish light*, a phenomenon resulting from the *refraction* of the solar rays by the *earth's atmosphere*. For the solar beams entering our atmosphere are refracted towards the earth, and being thus *bent into* the *shadow* pass onward and strike the moon. Being thence reflected to us, they are still sufficiently bright to render her surface, even in *shadow*, distinctly visible. The *color* of the light is owing to the same cause that gives rise to the ruddy tints of sunset clouds; the white light of the sun in struggling through the atmosphere loses its feebler rays,[1] while the *red*, which possesses the greatest power to overcome any resistance it encounters, *emerges*, and imparts its own hue to the objects upon which it falls.

This *reddish* light is of sufficient intensity, to enable observers to detect the *obscure* regions and *spots* on the lunar disk. The following facts are stated by Hind. During an eclipse of the moon that occurred on the 23d of July, 1823, M. Gambart saw all the *lunar spots* distinctly revealed. In an eclipse that happened on the

1. When a sunbeam is refracted, the seven colors of which it is composed; to wit, *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*, are *turned out* of the course of the original beam. The *red* deviating the *least* and the *violet* the *most*. The red is therefore *least* affected by the resistance it meets with.

Why? What does the duration of complete eclipse depend upon? How long may a lunar eclipse last, counting from the time the moon enters to the time she leaves the penumbra? What phenomenon occurs during a lunar eclipse? How is it caused? To what is the color owing? What can be discerned on the disk of the moon by means of this light?

26th of December, 1833, Sir John Herschel observed, that the moon was clearly visible to the naked eye, when completely *immersed* in the earth's shadow; gleaming with a *swarthy copper hue*, which changed to *bluish green* at the edges, as the eclipse passed away. Similar phenomena were noted during the *total* lunar eclipse of March 8th, 1848.

The spots on the surface, even at the middle of the eclipse were distinctly seen by many observers, and the general color of the moon was a *full glowing red*. So clearly did the *lunar disk* stand forth to view, that many of the observers doubted if there was any eclipse at all.

359. EARLIEST OBSERVATIONS OF LUNAR ECLIPSES. Observations were made on lunar eclipses at Babylon, by the Chaldeans, in the years 719 and 720 B.C. They relate to *three* eclipses, and are the earliest observations of this kind, in the annals of science. The *first* eclipse occurred on the 19th of March, 720 B.C., and was *total* at Babylon. The *second* happened on the 8th of March, 719 B.C., and the *third*, on the 1st of September in the same year; *both* were *partial* eclipses.

ECLIPSES OF THE SUN.

360. An *eclipse of the sun* takes place when the moon in her revolution about the earth, *comes between the earth and the sun*, and casts her shadow upon the *former*; concealing from our view, by her interposition, either a *part* or the *whole* of the bright disk of the sun. A *solar eclipse* can therefore only occur at the time of *new moon* or *conjunction*; and as in the case of lunar eclipses, it would happen *every revolution*, if the plane of the ecliptic coincided with that of the moon's orbit. But this is not the fact, and a *solar eclipse* can therefore only take place when at *new moon* the lunar orb is *at* or *near* one of her nodes. The *greatest possible distance* of the moon from the node at which a solar eclipse can occur is 18° 36′.

361. FORM OF THE ECLIPSE. A solar eclipse may be

Detail the facts mentioned by Hind? Give an account of the earliest observations of lunar eclipses? What is the cause of a solar eclipse? At what phase of the moon can it only occur? Why not at every new moon? Where must the new moon occur? What is the *greatest* possible distance from the *node* that a solar eclipse can take place?

partial, *total*, or *annular*. It is *partial* when only a portion of the dark body of the moon interposes between the sun and a spectator upon the earth. *Total*, when the *apparent diameter* of the *moon exceeds* that of the *sun*, and the former body passes nearly *centrally* across the solar disk. *Annular*, when the moon passes in like manner nearly centrally before the sun, but her *apparent diameter* is *less* than the *solar*; the entire body of the sun being then obscured with the exception of a *brilliant ring*, around the borders of the moon. When in this case the centres of the *sun*, *moon*, and *earth* are exactly in the *same straight line*, the eclipse is termed *annular* and *central*, and the bright ring possesses a uniform breadth.

362. Shadow of the Moon. The distance of the moon from the sun is subject to variation, and this circumstance affects the *length of the moon's shadow.* The *farther* this orb is from the sun the *longer* will be her shadow, and the *nearer* the *shorter.* Now when, during a solar eclipse, the *earth* is *nearest* to the *sun*, and the *moon* is *farthest* from the *earth*, the lunar shadow will be the *shortest*; but when the *earth* is *farthest* from the *sun*, and the *moon* is *nearest* to the *earth*, it will be the *longest.* That such must be the case is evident; for in the *first* instance the orbitual motions of the earth and moon bring the *latter* as *near as possible to* the *sun*, and in the *second*, remove her as *far as possible* from this luminary. In astronomical language the lunar shadow is therefore *shortest*, when the *earth* is at her *perihelion* and the *moon* in *apogee*, and *longest*, when the *earth* is at her *aphelion* and the *moon* in *perigee.*

363. The *average length* of the moon's shadow is found to be about *equal* to her *mean distance* from the *earth.* It will accordingly, for the reasons above assigned, at times *fall short* of the earth, while at others it will be so much extended, that a shadow of considerable breadth passes over the surface of the globe.

364. When the shadow *does not* reach the earth, it is

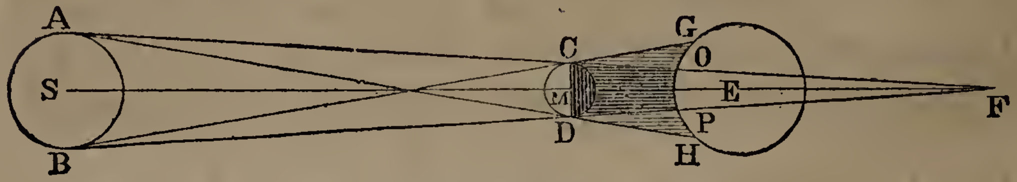
What is stated respecting the form of a solar eclipse? When is it *partial?* When *total?* When *annular?* When *annular* and *central?* State the cause of the variations in the length of the moon's shadow? When is it *shortest?* When *longest?* Give the same statements in astronomical language? To what is the average length of the moon's shadow nearly equal? What happens if it is *less* or greater than the mean length?

manifest *no total eclipse* can occur; although the sun, moon, and earth are so situated in every other respect as to give rise to this phenomenon. When it *does* reach the earth, the space that it covers on the surface of the latter, will depend upon the position of the *end* of the shadow in reference to the *surface* of the earth. If the *end* of the shadow just *touches* the earth, there will be a total eclipse only at the place it touches. But if the point where the shadow would terminate, if the earth did not interpose, is situated, as at F in Fig. 62, *far* on the *other side* of the *earth*, then the eclipse will be visible throughout a region of considerable extent. The *largest extent* of surface on the earth, covered *at once* by the *shadow of the moon* is about 180 miles in diameter.

365. The lunar shadow like that of the earth, has also its *penumbra*, which partially obscures our globe. The greatest breadth of terrestrial surface enclosed by the penumbra is nearly 5,000 miles.

366. In Fig. 62, this subject is illustrated, S here rep-

FIG. 62



SOLAR ECLIPSE.

resents the *sun*, M the *moon*, and E the *earth*. The *form* of the shadow is defined by the lines CF and DF, a portion of the shadow is however cut off by the interposition of the earth. The *breadth* of the shadow *on* the earth is represented by the distance from O to P, and the *breadth* of the *penumbra* on each side of the shadow, by the curved lines GO and PH.

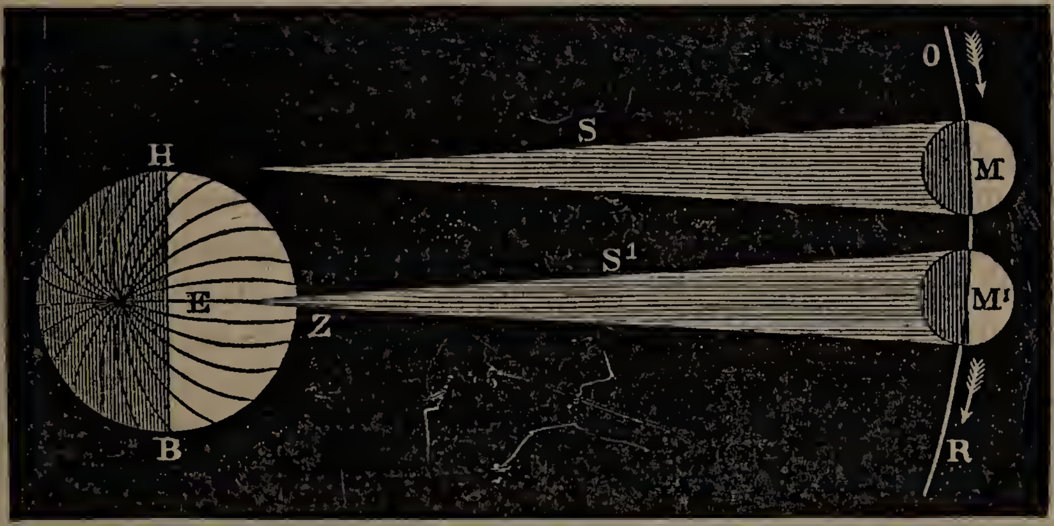
367. ALTITUDE OF THE MOON—ITS EFFECT ON ECLIPSES. Since the moon is *nearer* to the surface of the earth when in *the zenith* than when upon the horizon, by about

When will no total eclipse occur? Upon what does the extent of terrestrial surface covered by the shadow depend? Give the two illustrations? What is the greatest extent of surface obscured by the shadow? State what is said respecting the penumbra and its breadth?

4,000 miles, it *may* happen that a *total* eclipse takes place in one part of the world, and not in another. Two places may be so situated that the moon is on the *horizon* at *one* station and in the *zenith* at the *other*, when a *solar eclipse* is about to happen. Now it is possible that the *lunar shadow* may *fall just short* of the place where the moon appears upon the *horizon*, but as the *other station* is *nearer* to the moon by about 4,000 miles, the shadow may reach the *latter* place, and the sun will consequently for a short time be there *totally* eclipsed.

368. This phenomenon is illustrated by Fig. 63.

FIG. 63.



ALTITUDE OF THE MOON—ITS EFFECT ON ECLIPSES.

Here ZBHE represents the earth, OR the moon's orbit, M and M¹ two positions of the moon, and S, S¹ her *shadow*. To a spectator at H, the moon M is on the *horizon*, and there is no *total* eclipse, for the shadow does not reach him, but when the moon in her orbitual motion is at M¹ she is in the *zenith* to a spectator at Z, and the shadow reaches him causing a *total eclipse*,[1] though

1. The *distance* between the centres of the moon in the two positions M and M¹ is *equal* to the distance between the extremities of S, S¹, i.e., to the *radius* of the earth, or about 4,000 miles. By dividing the *length* of the moon's orbit by the *time* of her revolution, we obtain her *velocity*, which is more than 2,000 *miles per hour*. The moon therefore moves from M to M¹ in less than *two hours*, and the *shadow* is likewise carried from S to S¹ in the *same time*.

Explain how the *altitude* of the moon modifies eclipses? Explain from Figure

the shadow is of the same length as when the moon was at M.

369. For the reason just given an eclipse which would be *annular* to a person beholding the moon upon the *horizon* might be *total* to one observing her at the zenith.

370. TOTAL ECLIPSE OF THE SUN. We have remarked that eclipses of the sun and moon are among the grandest phenomena in nature, but no form of eclipse is so impressively sublime as a *total eclipse of the sun*. The gradual withdrawal of the solar light, and at length its total extinction; the oppressive and unnatural gloom that overspreads the earth, so different from the obscurity of night, and the appearance of the stars, at such an unusual time, all impress the mind with a deep solemnity. It is not surprising that a spectacle of this kind has ever filled barbarous and even civilized nations with astonishment and dread, as though they were on the brink of some awful calamity.[1] But *eclipses* whether total or otherwise are the source of one of the noblest triumphs of science; for astronomers are now so well acquainted with the laws, that regulate the motions of the heavenly bodies, that the very minute of an eclipse can be predicted centuries before it occurs, and the dates of events which happened thousands of years ago, can be unerringly fixed, by retrograde calculations of these phenomena.[2]

1. A total eclipse of the sun occurred during the war between the Medes and Lydians, related by Herodotus. In the midst of a battle, the sun was blotted out from the sight of the contending armies, and so great was their terror at such a strange event that they threw down the weapons, and made a peace upon the spot. This eclipse is said to have been predicted by Thales.

2. When Agathocles, the tyrant of Syracuse, invaded Africa, for the purpose of attacking the Carthagenians in their own country, a total eclipse of the sun occurred at the time the expedition was setting sail. This circumstance disheartened the soldiers, but Agathocles revived their courage by representing that this event portended the defeat and ruin of their enemies. This eclipse occurred according to retrograde calculations on the 15th of August, 310 B.C. An eclipse of the sun also happened at the very time Xerxes set out from Sardis, to invade Greece. The eclipse proves that this

May an *annular* eclipse in one part of the world be *total* in another? What is said in respect to a total eclipse of the sun? How have they been regarded by barbarous and even civilized nations? What have they proved to astronomers?

371. During a total eclipse of the sun, many singular appearances are usually observed. Soon after the eclipse has commenced, and as it gradually advances, jets of *light* are sometimes seen flashing over the lunar disk; and as the total obscuration approaches the bright portion of the sun changes color by degrees, either becoming fainter than before, or else assuming a *reddish tinge.*

When the sun is completely hidden, a beautiful *ring* or *corona*[1] of light appears around the dark body of the moon, like the crown of light or *glory* with which painters surround the heads of saints. In the eclipse of 1842, one observer describes it as a *ring of peach-colored light*, another as *white*, and a third as *beaming* with a *yellowish hue.* Its breadth likewise does not always appear to be the same; for in the eclipse just mentioned, while some observers estimated the width at one eighth of the moon's diameter, others saw radiations of the corona *eight times as long as* the *moon's diameter.* The breadth of the corona, noticed by Mr. Bond, during the eclipse of July 28, 1851, was about *one half* of the sun's diameter.

372. But the most brilliant phenomena remain to be described. When the sun is completely concealed, and the corona is displayed, *rose colored flames* appear to dart out from the edge of the moon, emanating from the bright ground of the corona, and so distinct that they are frequently visible without the aid of the telescope. They vary from *two* to *four* in number, and though mainly of a rose color, yet they are seen tinged with *lilac, greenish blue*, and *purple.* During the eclipse of July 28th, 1851, Prof. Bond of Cambridge, noticed these beautiful *rose colored* flames, *two* of which were connected by an *arch of light*, resembling a *rainbow.*

373. Fig. 64, represents this eclipse as seen by Mr. J.

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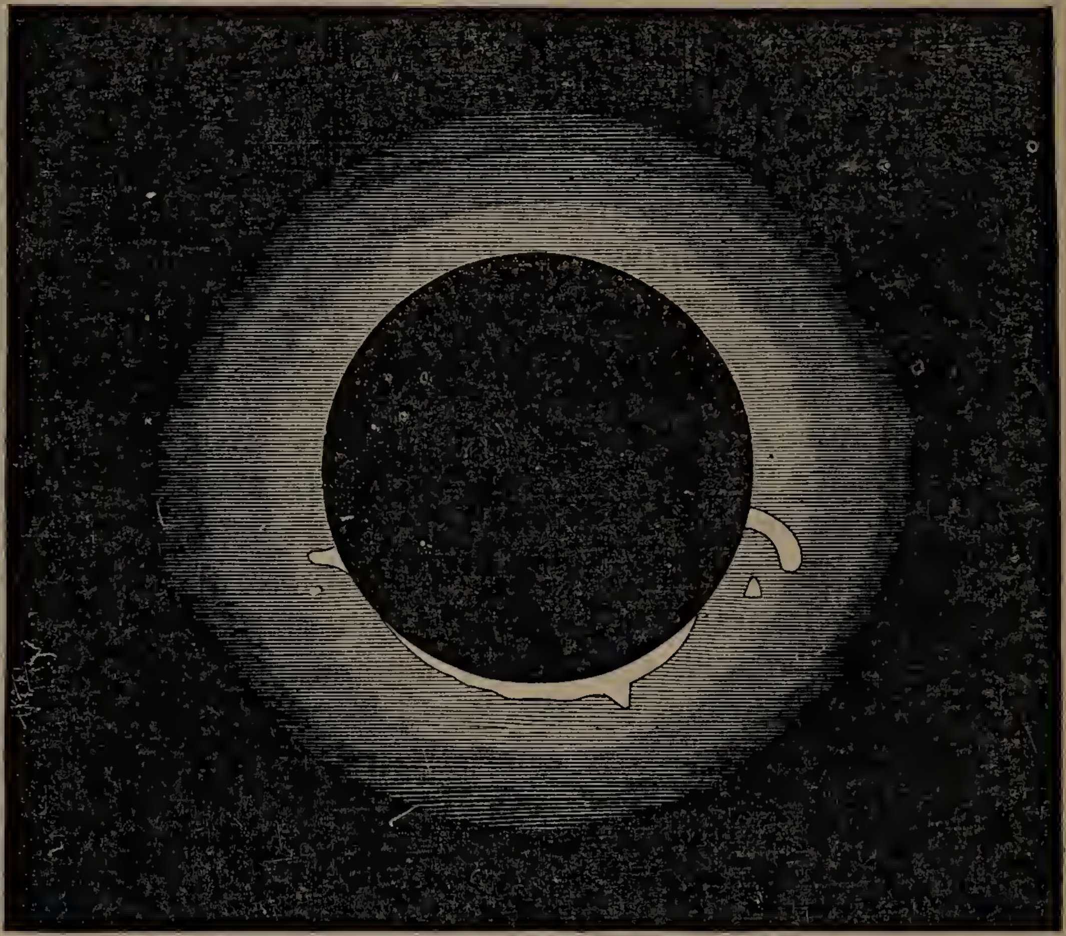
historical event occurred on the 19th of April, 481 B.C. A lunar eclipse which happened on the 21st of September, 331 B.C., fixes the date of the battle of Arbela, in which Alexander triumphed over Darius, king of Persia. The eclipse occurred 11 days before the victory.

1. *Corona*, a Latin word signifying *a crown.*

Describe the various appearances that are beheld during a total eclipse of the sun? What appearances were observed by Mr. Bond, during the eclipse of July 28th, 1851.

R. Hind, in Sweden. The eclipsed sun is here seen surrounded by a corona, the *whiter* portions of which near

FIG. 64



TOTAL ECLIPSE OF THE SUN, AS SEEN BY MR. J. R. HIND, NEAR ENGELHOLM, IN SWEDEN, JULY 28, 1851.

the dark circle indicate the positions of the *jets of flame* and the *arch of light.*

374. DURATION OF A SOLAR ECLIPSE. No eclipse of the sun can last longer than *six hours.* The duration of a *total* eclipse never exceeds *eight minutes*, nor that of an *annular twelve* and a *half minutes.*

375. SOLAR AND LUNAR ECLIPSES—POINTS OF DIFFERENCE. When a *lunar* eclipse occurs, it can be seen from every part of that side of the earth, which is *turned towards* the moon. For this hemisphere is necessarily in the earth's shadow, and a spectator here situated beholds the moon eclipsed when *she enters the shadow.*

Describe Fig. 64. How long can any eclipse of the sun last? How long a *total*? How long an annular eclipse?

376. In the case of a *solar* eclipse, the shadow of the moon passes across the earth in less than *four hours*, (Art. 368 note 1,) and an eclipse can only occur in the *path of the moon's shadow*. Every part of the terrestrial hemisphere turned toward the sun will not therefore be eclipsed, but only those portions that are traversed by the lunar shadow.

The extent and path of the shadow must accordingly be determined before we can know in what regions of the earth the sun will be eclipsed.

377. These differences in respect to *lunar* and *solar* eclipses, arise from the different positions of the *observer* in the two cases. During a *lunar eclipse* he is on the body that *forms* the shadow, during a *solar eclipse* he is on the body that *receives* the shadow.

378. FREQUENCY OF ECLIPSES. *Seven* is the *greatest number* of *eclipses* that can occur in the course of a *year*, and *two* the *least*. If *seven* take place *five* may be *solar* and *two* lunar or *three* may be eclipses of the *sun* and *four* of the *moon*. *Six* eclipses in a *year* is an *unusual* number, *four* the *average* and two the *least*; in the last case the eclipses will be *solar*.

379. An eclipse of the moon sometimes happens the next *full moon* after an *eclipse* of the *sun*, and the reasons are as follows. The solar eclipse taking place *at* or *near* one of the moon's nodes, the *shadow* of the *earth* extends at this time *across* the moon's orbit, and is *at* or *near* the *other node*. Now the moon's orbitual motion is so rapid that after causing the solar eclipse, she may sweep round to the *other* node, before the earth's shadow has departed so far from it, as to be out of the moon's way. Under these circumstances she enters the shadow and a *lunar eclipse* occurs.

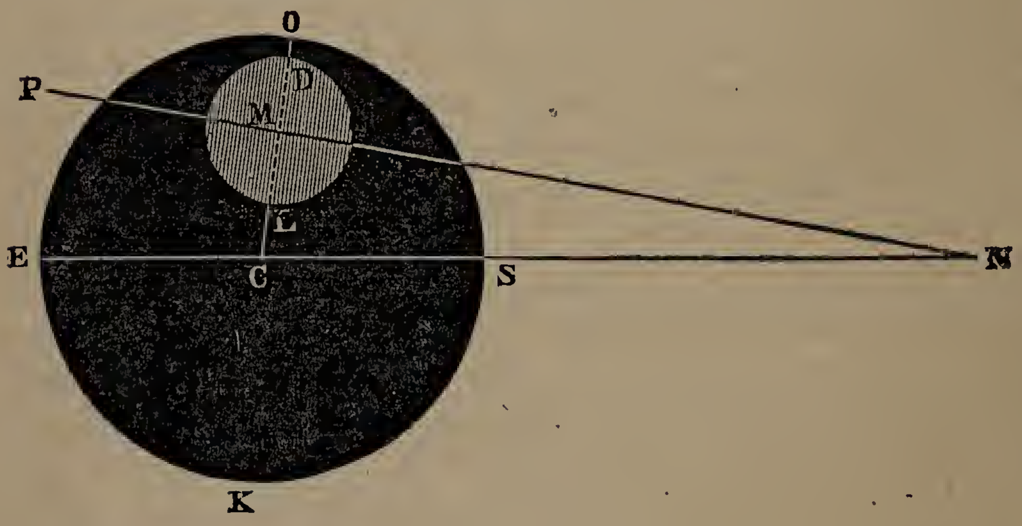
380. QUANTITY OF AN ECLIPSE. The *quantity* of an eclipse, is the *extent* of the *obscuration* of the eclipsed body, and is estimated in the following manner. In a

State in what respects *solar* and *lunar* eclipses differ? How do these differences arise? What is the *greatest* number of eclipses that can occur in a year? What the *least*? If seven take place what will be the number of solar eclipses, and what the number of lunar? What is an *unusual* number in a year? What the *average*? What the *least* number? If only *two* occur, are they solar or lunar? Explain why an eclipse of the moon may happen the next full moon after a solar eclipse? What is the *quantity* of an eclipse?

lunar eclipse, for example, the diameter of the moon is supposed to be divided into 12 *equal parts*, called *digits*, and the *number* of such parts that lie *within* the earth's *shadow*, at the time the moon's centre is *nearest* to the centre of the shadow, determines the *quantity* of the *eclipse*. When the moon is entirely immersed in the shadow, as in the case of a *total* eclipse, the quantity is found in like manner, by supposing a line to be drawn from the *centre* of the shadow to its *outer edge* through the *centre* of the moon, and then dividing the part included between the *inner* edge of the *moon*, and the *outer* edge of the *shadow*, by *one twelfth* part of the moon's diameter.

This subject is illustrated in Fig. 65, where M repre-

FIG. 65.



sents the moon, N one of her *nodes*, NMP a portion of the moon's orbit, and NSCE the direction of the plane of the earth's orbit. The *circle* EOSK is a section of the *earth's shadow*, which completely envelopes the moon, causing a total eclipse: the line OC is a radius of the circle EOSK and passes through the centre of the moon. The quantity of the eclipse is obtained by *dividing* the line LO by one twelfth part of DL the moon's diameter.

If the eclipse instead of being *total* had been *partial*, and the moon's centre M, had been at the point O, then

What is meant by the term *digit*? How is the quantity of an eclipse estimated? How is the *quantity* found in a total eclipse? Explain from Figure.

one half of her diameter ML would have been in shadow, and the quantity of the eclipse would have been *six digits.*

381. THE PERIOD OF THE ECLIPSES—THE SAROS. It was discovered by astronomers centuries ago, that if the eclipses that happen during a period of about 18 years, are noted in their order, that the series is *repeated* during the next period in nearly the same manner as before.

The reason of this will be evident from the following considerations.

382. We have seen that eclipses depend upon the nearness of the moon to her node when *new* and *full.* But the *node* is in motion around the ecliptic, retrograding at the annual rate of about *nineteen and a half degrees,*[1] while the *moon* is also in motion around the earth. Now an inquiry may reasonably be made whether, supposing that an eclipse was to take place to-day *exactly* at one of the moon's nodes, in which case, the sun and the moon would be in *the line of the nodes*, there might not be *such a relation* between the motion of the *moon* and the motion of the *node*, that after a *certain interval* of time another eclipse would again occur *at* the *same node;* so that the moon and the sun during the *next succeeding interval* would go through the same series of positions in respect to each other as during the *first*, and reproduce the same set of eclipses, resulting from these positions.

383. Such a relation is found to exist *very nearly.* For if there was to-day a solar eclipse, the sun and moon as seen from the earth, being *exactly* at one of the moon's nodes, the moon would be there *again* in [2]29.53 days (a *synodical* month, Art. 275,) and the earth in its revolution about the sun, would bring the same node again to the sun in 346.62 days, a period which is termed the

1. The *daily* retrogadation is 3′ 10″ (Art. 315,) which gives about $19\frac{1}{2}°$ for the *annual* rate.

2. This is the *expression* for the length of a *lunar month* in days and the decimals of a day. More nearly 29.5305887.

State what is said respecting the *period of the eclipses?* Explain in full the cause of this recurrence of a series of eclipses?

synodical revolution of the moon's nodes.[1] Now if 29.53 was precisely contained in 346.62, at the *end* of this time the sun and moon would be again at the *same node*, and the *same set of eclipses* would recur at intervals of 346.62 days. This however is not the case, since 29.53 is *not exactly* contained in 346.62, but if we multiply 29.53 by 223 and 346.62 by 19, the products will be respectively 6585.32 and 6585.78. 223 *synodical months* are therefore almost equal in length to 19 *synodical revolutions of the node.* If therefore an eclipse happens on any day when the sun and the moon are exactly in the line of the lunar nodes, the two bodies will be again precisely in the same position, within *less than half a days* time, after a period of about 6585½ days, or nearly 18 years and 11 days. At intervals therefore of 18 years and 11 days eclipses recur in nearly the same order.

384. This period, obtained by *observation* independently of theory, is supposed to have been known to the Chaldeans under the name of *Saros*, and that it was employed by them to predict eclipses: within it there usually occur 70 eclipses, 29 *lunar*, and 41 *solar*.

CHAPTER IV.

CENTRAL FORCES AND GRAVITATION.

385. We have shown in the preceding pages, that the *earth revolves* about the *sun*, and that the *moon* in like

1. The earth in her annual revolution completes the circuit of the ecliptic, or 360° in about 365 days, advancing from *west* to *east* at the *daily* rate of nearly 1°, but the lunar nodes *retrograde* from *east* to *west* at the *yearly* rate of nearly 19½°. If therefore to-day one of the nodes coincided in position with the sun as seen from the earth, this coincidence would *next* occur when the earth *lacked* about 19½° of completing her annual circuit, and as she moves in her orbit about 1° *a day*, the interval of time between these two coincidences is nearly 346.62 days, more accurately 346,619,851.

What is meant by a synodical revolution of the moon's nodes? What is the length of the period of the eclipses? What ancient astronomers are supposed to have employed this period in the prediction of these phenomena? What did they call it? How many eclipses usually happen within this period? How many of these are *lunar?* How many *solar?* What is the subject of Chapter IV.?

manner, describes an *orbit* around the earth. All the other members of the solar system have also their respective orbits, and possibly the *sun itself*, with its attendant planets and comets, *revolves* around some *vast central body* in the depths of space.

386. In view of these facts an interesting suggestion arises; viz., WHAT ARE THE FORCES WHICH CAUSE ONE HEAVENLY BODY TO REVOLVE ABOUT ANOTHER?

This point we will now investigate before we proceed farther in the discussion of the solar system.

387. When a body revolves about another as its centre, we find that it is influenced by *two* forces, one of which tends to make it *fly away* from the central body, and the other to *approach* it. The *former* is termed the *centrifugal*[1] force, the *latter* the *centripetal*.[2]

388. If a person fastens a bullet to one end of a string and then holding the other in his hand whirls the bullet around, it describes its *circular* path under the action of the two kinds of forces just mentioned. If the string were suddenly cut while the bullet was revolving, the latter would speed away from the centre of its orbit (the hand) like a stone from a sling. The force which thus actuates it, is its *centrifugal force*. Now when the string was *whole*, the bullet was prevented from obeying this centrifugal force, and kept in its circular path by the *resistance* of the string, which virtually drew the bullet *towards* the centre of its orbit, with the *same power* that the *centrifugal* force then tended to draw it *away*. The *tension of the string* is therefore the *centripetal* force.

389. Let us advance one step further. We can imagine that the hand of the person instead of being connected with the bullet by any *material* bond as a string, draws the bullet *towards it* by an *attractive power* that resides within it, just as a magnet draws to itself

1. *Centrifugal* from the Latin, *centrum*, a centre and *fugere* to flee away.

2. *Centripetal* from the Latin *centrum*, a centre and *petere* to seek.

What has been shown in the preceding pages? What inquiry arises in view of these facts? When a body revolves about another as its centre, how many forces actuate it? What are they called? Give the illustration? Which is here the *centrifugal*, and which the *centripetal* force? What can we next imagine?

any particles of iron that are near it. We can moreover suppose, that the attractive power is so adjusted in amount to the centrifugal force that it *exactly counteracts* the effort of the latter to make the bullet deviate from a circular path. Under these circumstances, the combined influences of the *centrifugal* and *attractive* forces, would cause the bullet to revolve in a circular path around the hand of the experimenter, without the intervention of a string.

390. Now a heavenly body revolves about its central orb, by the action of *centrifugal* and *centripetal* forces, like the bullet in the preceding illustration. But no solid substance, no material chain or rod connects the earth or any other planet with the sun, restraining its centrifugal force, and keeping it in its path in its ceaseless circuits, around this mighty orb. What then is the *nature* of the *centripetal force*, which causes a heavenly body to move with unerring precision in its orbit? Does there *actually exist* in the central body as we have *imagined* an *attractive power*, which constitutes the *centripetal* force? Let us see if this is the case.

391. OF GRAVITY. When a body falls from rest towards the ground it descends in a *straight line* in the direction of the centre of the earth, under the influence of what is termed the *force of gravity.*

There accordingly resides in the earth a power, which tends to *draw* other bodies towards its centre: in other words a *centripetal force.*

392. We recognize its action in the paths described by projectile[1] bodies, for when a cannon ball is fired into the air, if it was influenced by no other force than that of projection, it would continue forever to speed away from the earth, in a *straight* course. But owing to the action of gravity the body is drawn to the earth, de-

1. By *projectile bodies* is here meant those which are impelled forward by force through the air. This force is called the *projectile force.*

What may we suppose to be the relations of the attractive and centrifugal forces to each? How would the bullet then move without the aid of the string? What forces cause a heavenly body to revolve around its central orb? What inquiries are here made? When a body falls from rest what direction does it take? What is that force termed which causes it to descend towards the earth? What kind of power then resides in the earth? In what do we recognize its action? If the projectile force alone existed, what would be the path of the body? In consequence of gravity what is its path?

scending to it in a *curved* path, *concave* towards its surface.

393. The *greater* the *projectile* force the *greater* will be the *space* passed over by the body before it reaches the ground; and we may imagine the impulse to be so powerful as to carry the body completely around the earth to the point from whence it started. In this case, the projectile force remaining the same, the body would recommence its circuit and continue to revolve around the earth like the moon.

394. ITS VARIATION. The force of gravity above the surface of the earth, *varies inversely as the square of the distance from the earth's centre.* By this expression we mean that if gravity exerts at the surface of the earth for instance, or about 4,000 miles from the centre a *certain power*, it will exert at *twice this distance* from the centre, or 8,000 miles, only *one fourth* of this power. Thus, at the surface of the earth, a body descends freely under the action of gravity $16\frac{1}{12}$th *feet per second*, but at the distance of 8,000 miles from the earth's centre, it will fall through only *one fourth* of this space in a second, or $4\frac{1}{48}$th *feet.*

395. This *law* is illustrated in Fig. 66, where A represents the centre of the earth, BCDE a square portion of its surface, and BA, CA, DA, and EA the *lines of direction* in which gravity acts. Suppose these lines are extended to F, G, H, and I, and the square FGHI is formed, whose distance from A is *twice* that of the square BCDE. Now it is manifest that the *amount* of gravity which is contained in the *first* square BCDE is the *same* as that which is contained in the second square FGHI, but its *intensity* or *strength* in the *latter* is as much *less* than that in *former*, as the square FGHI is *greater* than BCDE. But FGHI contains *four small* squares *each equal* to BCDE, therefore, the intensity of the force of gravity at F, which is *twice* as far from the centre as B, is *one fourth* of what it is at B. If we construct *another figure* JKLM at *four times* the distance of B from A, it will

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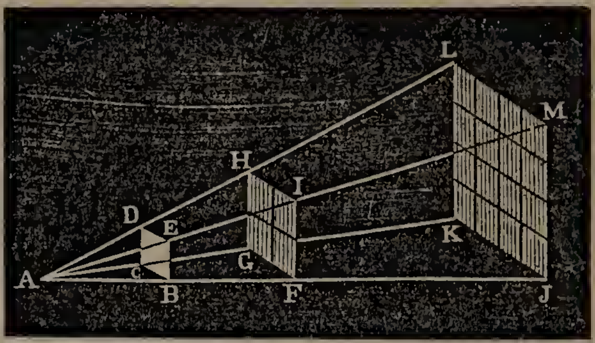
If the projectile force is increased, what is true in regard to the extent of space *passed* over by the body? If the impulse was so great that the body passed round the earth to the place where it started, what would happen? According to what law does gravity vary? What is meant by this expression? Explain from Figure.

FIG. 66.



THE FORCE OF GRAVITY VARIES INVERSELY AS THE SQUARE OF THE DISTANCE.

contain *sixteen squares* each equal to BCDE, and the force of gravity will here be *diminished sixteen times ;* all which accords with the rule just stated.

396. The change in distance must be great, for the *variations* in the force of gravity to be *appreciable.* It is therefore regarded as a *constant* force at every part of the earth's surface, for the *difference* in the distances from the earth's centre, at the sea level and upon the loftiest accessible heights is *too small* to cause any material variation in the force of gravity.

397. In the beginning of the 17th century, Kepler discovered by his unconquerable energy of mind, those famous laws which still bear his name, (Art. 193,) one of which announces *that the planets revolve in elliptical orbits around the sun*, which occupies a common focus.

But though his perseverance was crowned with such success, he *knew not* the controlling *force* which holds the planets to the sun, and keeps them in their orbits. The glory of this discovery was reserved for another whose genius has illumined the whole field of science.

398. Universal Gravitation discovered. In the year 1666, when the plague made such fearful ravages in England, the illustrious Newton retired from Cambridge, where the pestilence then raged, to his country house at Woolsthorpe. While sitting one day alone in his garden, the fall of an apple led him to reflect upon the nature of *terrestrial gravity.* He already knew that

Are the variations in the force of gravity perceptible when the differences in the distances are small? Where is gravity regarded as a constant force, and why? When did Kepler discover those laws which bear his name? Did he ascertain what that force is which control the motions of the planets?

it caused the path of a projectile to be curved towards the earth, and that it was as sensibly powerful upon the tops of lofty mountains as at the sea level; and he conceived that if it existed on the highest points of the globe without any perceptible diminution, it might possibly extend much farther. Then it flashed upon his mind that the moon perhaps was retained in her orbit by such a power, and that the force of gravity at so great a distance from the earth would probably be diminished. He likewise imagined, that if the moon was kept in her path by this controlling force, that the planets might also revolve about the sun in obedience to the same power.

399. From the third law of Kepler; viz., *that the squares of the periodic times of the planets are as the cubes of their distances from the sun*, he inferred that this *binding force varied inversely* as the *square* of the *distance* from the *centre* of the *attracting body.*

400. With these views the astronomer now proceeded to investigate the orbitual motion of the moon, by comparing the *space*, which a body falls through in *one second of time*, at the earth's surface, with the *space* that the moon would be drawn towards the earth in the *same time*, under the action of gravity; diminished in the inverse ratio of the square of the moon's distance from the earth's centre.

401. This calculation was not at first satisfactory, because the correct length of the earth's diameter was not then known. *Sixteen years* afterwards when the true length was ascertained, Newton repeated his computation, and now his most sanguine hopes were fully realized. The force of terrestrial gravity diminished in the inverse ratio of the square of the moon's distance, from the earth's centre, was proved to be the very force that keeps this luminary in her orbit.

402. The method of investigation pursued was the following: The moon, starting from any point in her orbit, would move away from the earth in a *straight line*, if

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Relate the manner in which Newton was led to the discovery that gravity extended to the moon? How did the astronomer proceed to investigate the moon's orbitual motion? Was the calculation at first satisfactory? Did it afterwards prove so?

some centripetal force did not *deflect* her, and cause her to move in *a curve*.

The *amount* of this *deflection* is therefore a *measure of the centripetal force*, and when we know the moon's distance from the earth we can calculate the *amount* of this *deflection* for any given time, as *one second;* in other words through what *extent of space* the moon *descends* toward the earth in *one second.* Having ascertained this point, we next proceed to inquire if this *unknown force* is the *force of gravity.*

403. Gravity at the earth's surface, causes a body to fall freely through a space of $16\frac{1}{12}$th *feet* in *one second,* as before stated, but the moon is removed 60 times farther from the centre of the earth than is the surface of the latter. Therefore, if gravity extends to the moon its force will be 3,600 (60×60) *times less* than it is at the earth's surface, and the space a body would fall through at the moon under its influence, during one second, would be found by dividing $16\frac{1}{12}$th feet by 3,600. The quotient thus obtained is .052 inches, a result *identical* with the computed *amount* of *deflection.* It is therefore inferred that the *centripetal* force which causes the moon to revolve about the earth *is the force of gravity.*

404. The path of research opened by this grand discovery was not neglected. Succeeding researches have proved that the influence of gravity extends to all the bodies of the solar system, and even to the *fixed stars.* Every portion of matter whether large or small, a *world* or a *grain of sand,* is found to possess this attractive force and to be under its control. *One* body *attracts another* and is itself in turn attracted by it, the earth gravitates towards the sun, and the sun towards the earth; the *amount* of attraction exerted by any body, being *proportioned* to the *quantity of matter contained* in that body.

405. The investigations of astronomers, tend to show that *gravity* is *coextensive* with the *material universe,* and in view of its boundless diffusion, it has received a new appellation, being termed *universal gravitation;* A POWER

Detail the mode of investigation? Through what space will a body fall in one second at the distance of the moon from the centre of the earth? Does gravity extend in its influence beyond the moon? What do we now know respecting it? What is it termed in in view of its wide diffusion?

IN VIRTUE OF WHICH ALL BODIES MUTUALLY ATTRACT EACH OTHER IN THE DIRECT RATIO OF THEIR QUANTITIES OF MATTER, AND IN THE INVERSE RATIO OF THE SQUARES OF THEIR DISTANCES FROM EACH OTHER.

406. In addition to what has already been stated, this great principle accounts for the *spherical form* of the heavenly bodies, for *nutation*, the *precession of the equinoxes*, the *change in the obliquity* of the *ecliptic*, the complex *lunar motions*, and various other celestial phenomena of which we shall hereafter speak.

CHAPTER V.

THE PLANETS.

407. THE *planets* are those heavenly orbs that revolve directly about the[1] sun, from *west* to *east*, and shine by its reflected light. They have received this appellation, as we have stated, (Art. 2, note 1,) from the fact that they are seen moving among the fixed stars, and are constantly changing their places in the heavens.

408. The names of the different planets have already been given, (Art. 7.) Mercury, Venus, Mars, Jupiter, and Saturn, have been known from the earliest ages; for they are visible to the naked eye, and all but Mercury conspicuously so. The *rest* of the planets, 78 in number, excluding the Earth, are recent discoveries; all of these having been found since the year 1780, and 73 of them within the last 18 years.

409. Many of the planets are attended by *moons* like the earth. The Earth, as we know, has *one* moon, Jupi-

1. The planetary bodies that revolves *directly* about the sun are called *primary* planets. *Moons* are termed *secondary* planets. The body about which another *directly* revolves is denominated its *primary*, thus, the *sun* is the *primary* of the *earth*, and the *earth* the *primary* of the moon.

What is universal gravitation? What is further said of this great principle? What are *planets*? Why are they so called? Which have been known from a high antiquity? How many have been discovered since the year 1780? How many within the last 17 years?

ter *four*, Saturn *eight*, Uranus *six*, and Neptune *one*. Up to the present time, the known number of *planets*, including the Earth, is 84, and of *moons* 20.

There doubtless exist other planetary bodies in our system yet undiscovered, if we can infer any thing from the harvest of planets that has lately rewarded the searching labors of zealous astronomers.

410. DISTANCES. The respective distances of the planets from the sun, beginning with *the nearest* to this luminary, are presented in the following table:

TABLE OF DISTANCES.

	Miles.
*Mercury,	36,890,000
Venus,	68,770,000
Earth,	95,298,260
Mars,	145,205,000

THE ASTEROIDS.

	Miles.
Feronia,	203,783,740
Flora,	209,131,670
Ariadne,	209,364,610
Harmonia,	215,379,060
Melpomene,	218,125,700
Victoria, or Clio,	221,617,045
Euterpe,	222,993,975
Vesta,	224,327,205
Urania,	224,598,905
Nemausa,	225,901,640
Metis,	226,644,350
Iris,	226,683,965
Echo,	227,203,995
Ausonia,	227,654,200
Daphne,	228,032,015
Phocœa,	228,100,700
Massilia,	228,891,670
Asia,	229,421,200
Hebe,	230,414,710
Nysa,	230,886,670
Isis,	231,219,455
Lutetia,	231,365,945
Fortuna,	231,929,960
Parthenope,	232,995,860
Thetis,	235,002,450
Calliope,	237,080,005
Hestia,	241,296,960
Amphitrite,	242,712,270
Galatea,	244,645,135
Egeria,	244,684,375
Astræa,	244,767,500
Melete,	245,428,700
Pomona,	245,958,705
Irene,	245,989,960
Calypso,	248,224,930
Thalia,	249,738,280
Fides,	250,981,165
(Not named,)	251,121,955
Eunomia,	251,197,100
Virginia,	251,844,430
Maja,	252,117,278
Proserpine,	252,327,505
Juno,	253,524,410
Panopœa,	253,662,065
Angelina,	254,437,170
Circe,	255,388,690
Concordia,	255,971,895
Olympia,	259,714,955
Leto,	258,652,510
Alexandra,	258,811,540
Leda,	260,270,075
Eugenia,	260,568,660
Atalanta,	261,126,975
Niobe,	261,841,470
Ceres,	262,764,110
Lætitia,	263,091,765
Pallas,	263,186,670
Bellona,	263,641,815
Pandora,	263,965,195
Polymnia,	272,372,125
Aglaia,	273,641,325
Psyche,	277,661,440
Leucothea,	283,216,755
Danae,	285,377,815
Hesperia,	290,924,010
Pales,	293,180,925
Europa,	294,330,710
Doris,	295,150,275
Erato,	297,430,750
Hygeia,	299,190,435
Themis,	299,244,965
Euphrosyne,	299,835,010
Mnemosyne,	299,942,265
Cybele,	325,996,965
Clytia,	
Freya,	

Jupiter,	495,817,000
Saturn,	909,028,000
Herschel, or Uranus,	1,828,071,000
Neptune,	2,862,457,000

411. So vast are the numbers expressing the distances of the planets from the sun, when a *mile* is taken as the *unit of measurement*, that the mind can scarcely grasp their meaning, and it is difficult to form a true conception of the immense spaces that separate these bodies from their central orb. A clearer idea may perhaps be conveyed by taking a different *unit of measurement.*

412. From numerous experiments made by the American Coast Survey, it has been found, that the average velocity of electricity through the telegraphic wires is about 16,000 miles *per second.* If therefore, for example, London was united to New York by a telegraphic line, news could be sent from one city to the other in about *one-fifth of a second.* Now supposing the *sun* was connected with the *planets* by telegraphic lines, then the time it would take to transmit a message,

From the Sun to the Earth,		would be	1h. 39′
	to Jupiter,	"	8h. 36′ 28″
	to Saturn,	"	15h. 46′ 54″
	to Herschel,	"	1d. 7h. 44′ 14″
	to Neptune,	"	2d. 1h. 41′ 43″

413. The apparent diameter of a body being inversely proportioned to the distance (Art. 177,) at which it is viewed; it follows, that the *sun* will *appear* of *various* sizes, at the different planets. The *relative*

**Supposed new planet* VULCAN.—On the 26th of March, 1859, Dr. Lescarbauldt, of Orgeres, in France, beheld, moving across the sun's disk, a *small, circular*, and well defined *dark* object, which he regarded as a new planet in transit. Its apparent diameter was less than one-fourth of that of Mercury in transit.

Leverrier, who considers the existence of one or more planets within the orbit of Mercury as highly probable, regards the observations of Dr. Lescarbauldt as worthy of credit; and, upon the supposition that the planet moves in a circular orbit, estimates that its *solar orbit* is 135,500,000 miles, its *periodic time* 19d, 16h, and the *inclination of the plane of its orbit* 12° 10′.

The supposed planet has been named Vulcan.

How many planets have moons, and what is the number of moons that each of these respectively have? What is the known number of planets at the present time? What the number of moons? Are there reasons for believing that other planets will be discovered? Enumerate the planets and give their distances. What is said respecting our conception of these immense distances?

apparent magnitudes of this body as it would be seen from the principal planets are shown in Frontispiece.

414. KEPLER'S LAW OF DISTANCES. From the *third* law of Kepler; viz., that the *squares of the periodic times of the planets are as the cubes of their mean distances from the sun*, the *unknown* mean distance of a planet can be found, when its *periodic* time is ascertained together with the *distance* and *periodic* time of *another planet.*

Thus the *periodic* time of Mars having been ascertained by observation, to be 687 days, and the *distance* of the *earth* from the sun and her *periodic time* being known, the mean distance of the former can be found by the following proportion; viz., *the square of the earth's periodic time is to the square of Mars' periodic time, as the cube of the earth's distance is to the cube of Mars' distance.*

This proportion expressed in figures is as follows: 365.256 representing the length of the year in days and fractions of a day, and 95,298,000 the mean solar distance of the earth in miles. (365.256 [days] × 365.256): (687 [days] × 687): (95,298,000 [miles] × 95,298,000 × 95,298,000): (145,210,000 [miles] × 145,210,000 × 145,210,000.) The last term in the proportion is the cube of Mars' mean distance from the sun. The *distance* is therefore 145,210,000 miles.

415. In this way the *periodic* time of a planet can also be found when its *distance* is known, and also the *distance* and *periodic* time of another planet known. For reversing the terms of the proportion already given, the cube of the earth's solar distance is to the cube of Mars' solar distance as the square of the earth's periodic time is to the square of Mars' periodic time.

Take the velocity of the electric current as the unit of measurement, and give the different estimates of the planetary distances with this unit. What is said respecting the apparent size of the sun as viewed from the different planets? When can the distance of a planet be found by Kepler's *third* law? Give an instance. Can the *periodic* time of a planet be found by this rule?

416. The laws of Kepler are alike applicable to *moons and planets;* the *mean* distances of the former from the planets about which they revolve, can therefore be determined, as in the case of planets, by the law just mentioned. Comets are also governed by the same laws.

417. BODE'S LAW OF DISTANCES. A relation between the distances of the planets from the sun, was discovered in the latter part of the last century, by Prof. Bode of Berlin, it is termed Bode's law, and is thus expressed. If 4 is taken as the distance of Mercury from the sun, 4 added to 3 gives the relative distance of Venus, 4 added to 3 × 2, that of the Earth, and the relative distances of the other planets are found in their order by successively annexing 2 as a factor, thus,

			RELATIVE DISTANCES.
Mercury, ...	4		= 4
Venus, ...	4	added to	3= 7
Earth,....................	4	"	3×2= 10
Mars, ...	4	"	3×2×2= 16
Asteroids, (average distance,)	4	"	3×2×2×2= 28
Jupiter, ...	4	"	3×2×2×2×2= 52
Saturn,..................	4	"	3×2×2×2×2×2=100
Uranus, ...	4	"	3×2×2×2×2×2×2=196

418. This law gives the *actual* distances of the above planets with tolerable exactness, when that of one of them is known. For example, the relative distance of Mercury (4) : the relative distance of the Earth (10) : : the real distance of Mercury, (36,890,000 miles) : the distance of the earth (92,225,000 miles,) which is nearly the true distance. Bode's law fails in the case of Neptune.

419. MAGNITUDES. No relation has been discovered between the *magnitudes* of the planets by which the size of one can be ascertained, when that of another is known. These bodies differ very much in size, the *asteroids* being extremely *small,* while the bulk of others, as that of Jupiter and Saturn is *immense,* far exceeding the size of the earth. This subject with others of a kindred nature

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Is this law applicable to moons? State Bode's law? Is this law perfectly exact? Does it hold true in every case? When the magnitude of one heavenly body is known, can that of another be inferred? Do the planets differ much in size?

will be pursued farther in the subsequent pages, when each planet will be separately discussed. In Fig. 67, a view is presented of the *relative magnitudes* of the eight chief planets.

420. DIVISION OF THE PLANETS. The planets are usually divided into TWO CLASSES. First, the INFERIOR whose orbits are *within that* of the earth: Mercury and Venus constitute this class. Secondly, the SUPERIOR whose orbits *inclose* the earth's orbit; within this division are comprised all the planets from Mars to Neptune inclusive.

INFERIOR PLANETS.

421. The two planets Mercury and Venus are known to have their orbits within that of the earth; *First*, because they are never seen by us, like the other planets, in a part of the heavens *opposite* to that which the sun occupies, which would be the case if they included the earth within the circuit of their respective orbits.

422. *Secondly*, if viewed with a telescope, they present *phases* like the moon; being *crescent shaped*, when situated between the earth and the sun, and *full* when the sun is between them and the earth; and in other positions exhibiting every variety of phase between these two extremes. Phenomena which can be accounted for only on the supposition that these planets receive light from the sun, and move around it at a *nearer* distance than the earth.

423. *Thirdly*, because these bodies at certain times are seen *between* the earth and sun, appearing as *dark spots* on his disk, as they cross from one side to the other. Such an appearance is termed a *transit.*[1] When *either* of these planets is *between* the *earth* and the *sun*, it is said to be in *inferior conjunction*, when the *sun* is *between it and the earth* it is in *superior conjunction.*

1. ***Transit***, see Art. 103, note 2.

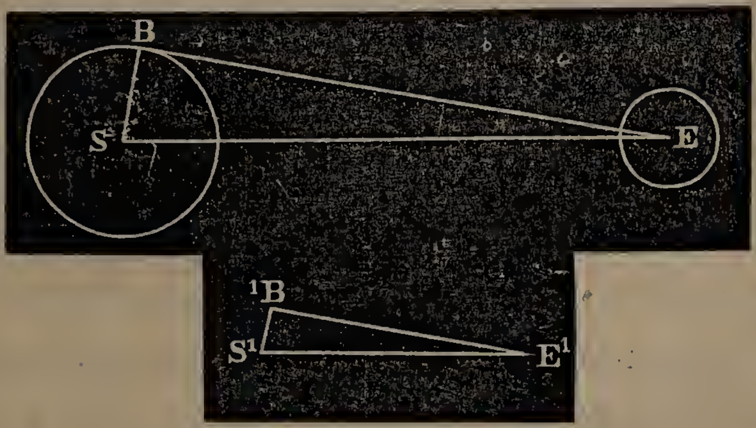
Into how many classes are the planets divided? What are they? What is meant by an *inferior*, what by a *superior* planet? How do we know that the orbits of Mercury and Venus are within that of the earth? What is the *interposition* of a planet between the earth and the *disk* of the sun called? When are these planets respectively in their *inferior* and *superior* conjunctions?

MERCURY. ☿

424. This planet is the *nearest* to the sun of any that have been discovered. Its greatest angular distance from this luminary never reaches 29°. For this reason, it can only be discerned in the gloom of twilight, either at morning or evening, according as it is to the *east* or *west* of the sun. Even under the most favorable circumstances, it does not appear conspicuous to the unaided eye, but shines like a small star beaming with a pale red light.

425. Distance of Mercury from the Sun. The distance of this planet from the sun in miles, may be found, independently of the methods already explained in this chapter, by observing its angular distance from the sun at the time of its *greatest elongation.*[1] It is computed as follows. Let B, Fig. 68, represent the position of

FIG. 68.



Mercury at this period, S the sun, and E the earth; draw the lines BS, SE, and EB, forming a triangle which will be right angled at B. The angle E, as taken by an in-

1. *Greatest elongation*, by this is understood the greatest *angular distance* that the *planet* departs *from* the *sun*, (as seen from the earth) while making a circuit around it. The greatest elongation in the case of Mercury occurs about 6 or 7 times a year. It never exceeds in extent as stated in the text 29° and is sometimes only about 16° or 17°.

What is said respecting the proximity of Mercury to the sun? What is the extent of its greatest angular distance from this orb? When can this planet be seen? When is it most conspicuous? What is its appearance? Explain how its distance from the sun may be calculated?

strument, we will suppose is 27°, and we know the length of the line ES to be about 95,000,000 of miles, because it is the distance of the earth from the sun. Proceeding then, as we have often done before, we select a similar triangle $S^1B^1E^1$, and calling E^1S^1 *one mile* we make the following proportion; E^1S^1 (one mile) : S^1B^1 (.45399ths of a mile) : : ES (95,000,000 miles): SB (43,129,050 miles.)

426. If the orbit of Mercury was a *perfect circle*, one computation like this would give the true distance of the planet from the sun at any part of its orbit; but Mercury revolves as the other planetary bodies in an *elliptical* orbit, and his distance from the sun is accordingly *variable.* By making the preceding calculation when the planet is in different points of its orbit, the *mean distance* is ascertained and found to be 36,890,000 miles.

427. Orbit—Inclination of its plane. The elliptical orbit in which Mercury moves, deviates very much from a circle. At its *perihelion* the planet is about 29,305,000 miles from the sun's centre, while at the *aphelion* its distance is no less than 44,474,000 miles. Its distance from the sun accordingly varies more than 15,000,000 miles; a change *five times* greater than that which exists in the case of the earth, (Art. 198.) The inclination of the plane of its orbit, to that of the ecliptic is about 7°.

428. Size—Apparent—Real. When Mercury is at his *perigee*, his *apparent* diameter is about 12″ but it decreases to 5″ at his *apogee.* Knowing the distance of Mercury from us, as well as his apparent diameter, it is easy to calculate his *real* diameter in the same way as we have computed that of the sun and moon, which has been repeatedly explained. From measurements taken with the utmost accuracy within the last few years, the diameter of this planet is estimated to be 2,950 miles.

Why will not one calculation give the true distance? How is the mean distance obtained? What is it? What is said respecting the orbit of Mercury? How far is this planet from the sun at its perihelion and aphelion? How great is the variation between the perihelion and aphelion distances? How does it compare with the variation existing in the case of the earth? What is the inclination of the plane of Mercury's orbit to that of the ecliptic? What is the apparent diameter of Mercury at its *perigee* and *apogee*? What is its actual diameter in miles?

Very little difference is found to exist between its *polar* and *equatorial* diameters.

429. PERIODIC TIME. Mercury revolves about the sun in nearly 3 months, or more exactly 87d. 23h. 15m. 44sec. The ancient astronomers by observing his return to the same position in the heavens approximated very closely to his true period of revolution. By the application of Kepler's third law the *periodic time* is readily ascertained in the manner explained in Art. 414.

430. ROTATION ON ITS AXIS. The powerful illumination to which this planet is subjected on account of its proximity to the sun, has thrown a degree of uncertainty upon all investigations respecting its physical characteristics. In consequence of this overpowering brilliancy it does not present in the field of the telescope a distinctly *defined disk.* The period also of observation is necessarily short, for in its rapid circuit, it soon approaches the sun, and is shrouded from our view beneath the intense splendor of the solar rays. Moreover, since all observations must necessarily be made when the planet is *near the horizon*, it is consequently discerned through that part of the atmosphere which is most subject to vapors, and is therefore liable to be seen *distorted* on account of the changeable nature of the medium through which it is observed.

431. For these reasons the reliable observations upon Mercury are few. Sir William Herschel, with all his ability and skill, obtained no conclusive proof of the existence of *spots* upon the surface of the planet which would have enabled him to determine the *time of its rotation on its axis.* Schroeter appears however to have met with better success. In the early part of this century he subjected Mercury to a most careful scrutiny and obtained, as he believed, decisive evidence of the existence of *mountains*, rising to the lofty altitude of more than 10 miles above the general surface of the planet. By noting likewise the variation in the appearance of

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Is there any observed difference between the lengths of the *polar* and *equatorial* diameters? What is the periodic time of Mercury? What is said respecting the observations of ancient astronomers upon this planet? Can the periodic time be obtained in any other way than by observation? State why it is difficult to ascertain with certainty the physical characteristics of this planet? Are there many reliable observations on Mercury? State what is said respecting Sir William Herschel's efforts? What success had Schroeter?

the *horns* of the planet, when it assumed a *crescent shape*, the same astronomer ascertained to his own satisfaction the fact of its *rotation;* the period of which he estimated at 24h. 5m. 28sec. Since the time of Schroeter no astronomer has gained any further information on these points, which future observations may modify or confirm.

432. PHASES. On examining Mercury with the telescope in different points of his orbit, we find that he presents *phases like* those of the moon in her revolution about the earth.

433. When near his *inferior conjunction*, or between the earth and sun, Mercury appears *horned* or *crescent shaped*, like the moon when *new;* since nearly the *whole* of his illuminated hemisphere is now *turned away* from us in the direction of the sun. Advancing in his orbit to his greatest *western elongation half of* the illuminated hemisphere is then seen by us, and the planet is in its *first quarter.* As it moves towards its *superior conjunction* it becomes *gibbous*[1] the *visible* bright portion gradually assuming a *circular* form, like the moon near the *full.*

434. On account of the surpassing splendor of the solar rays, Mercury is *invisible* for some time before and after the superior conjunction, but on emerging into sight on the other side of the sun, he is still *gibbous*, like the moon as she moves towards her third quarter.

When the planet has arrived at its greatest eastern elongation, it again appears as a *half moon*, like our satellite in her last quarter. As it approaches again its *inferior conjunction*, it dwindles once more to a *crescent;* but is lost in the blaze of the solar light for some time before and after passing this position.

435. TRANSIT OF MERCURY. If the plane of the orbit of Mercury was coincident with that of the ecliptic, the planet at *every inferior conjunction* would pass directly

1. See Art. 269, note 2.

What is the period of Mercury's rotation as determined by him? Have later astronomers increased our knowledge of the physical characteristics of Mercury? What phenomenon is observed in respect to this planet, when viewed with a telescope? Describe the phases of Mercury in full?

between us and the *disk of the sun*, and would appear as a *black spot* upon it. But since the plane of its orbit is inclined to that of the ecliptic about 7° degrees, this phenomenon does not occur at every inferior conjunction, for the planet may be *on one side of the disk of the sun* when it is in this position.

436. In order that a *transit* may occur, the *earth* must be in the *line of the nodes* of Mercury, *at* or *very near* the time when the planet passes through *one of them*, in its revolution about the sun. For Mercury being at the node is consequently *in the plane of the ecliptic*, and the *line of the nodes* will then pass through the *sun*, the *earth* and *Mercury*, and the latter, as seen from the earth, will be projected as a *dark spot* upon the sun; just as the moon is during a solar eclipse. If the *planet*, *the earth*, and *sun* are not exactly in the line of the nodes, still a *transit* may occur within certain limits, on account of the magnitude of the sun; the planet crossing the disk of the sun not through its *centre* but on one side of it.

437. The earth arrives at the line of the nodes *twice a year*, about the 10th of November and the 7th of May, and since the nodes move but about 13′ in *one hundred years* the transits of Mercury must for a long time happen in these months. The *last* transit occurred on the 8th of November 1848,[1] and the *second* after the next will happen on the 6th of May, 1878.

438. SPLENDOR OF MERCURY. The distance of the earth from the sun, is to the distance of Mercury from the sun in the ratio of about 8 to 3; and the *nearer* any planet is to the sun the *greater* is the *amount* of *light* it

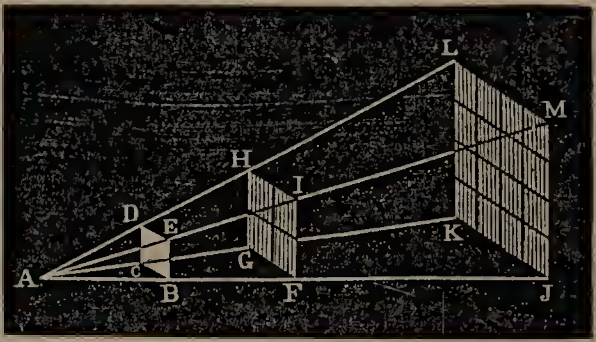
1. Respecting this transit, Prof. Alexander, of Princeton, thus speaks; "I observed that as the planet approached the sun it seemed to be united to it by a *dark fringe or penumbra.* During the progress of the transit Mercury was at times surrounded by a dusky ring. This occurred when the sun was slightly obscured by a thin haze. Occasionally also an obscurely luminous spot appeared upon the centre of the planet, this spot was united to the circumference by three fainter bands, symmetrically arranged."

Why does not a transit of Mercury occur at every inferior conjunction? What must be the respective positions of the planet and the earth that a transit may occur? Why? If these three bodies are not exactly in the *line of Mercury's node* can this phenomenon occur? Why? In what months do the transits happen? Why will they take place on these months for a long period? When did the last transit occur? When will the second after the next take place?

receives. The *intensity* of the solar light at any two planets is *inversely proportioned to the square of their distances from the sun*, accordingly the amount of light illumining a surface of *one mile square* on the planet Mercury is to that which falls upon the *same extent of surface* on the earth as 64 to 9. The *intensity* of light is therefore about *seven times greater* at Mercury than at the earth.

439. The law of the *decrease* of the *intensity* of light with the *increase* of distance, is the same as that which exists in the case of gravity (Art. 394,) and may be illustrated by the same figure. Let therefore A, Fig. 69,

FIG. 69.



THE INTENSITY OF THE SOLAR LIGHT VARIES INVERSELY AS THE SQUARE OF THE DISTANCE.

be a *point on the sun's surface* from which light emanates, falling upon the *squares* BCDE, FGHI, JKLM. FGHI is *twice* as far from A as BCDE, and contains *four times* as much surface; JKLM is *four times* as far from A as BCDE, and contains *sixteen times* as much surface. Now since the *same quantity of light* is diffused over each of the three squares, its *intensity* must be *four times greater* at the distance AB, than at the distance AF, and *sixteen times greater* than at the distance AJ.

440. The *apparent surface* of the sun, varies also according to the same law, and this luminary will consequently appear to the inhabitants of Mercury (if any there are) *seven times larger* than it does to us.

441. Mass and Density. The investigations of astronomers in respect to these particulars have led to the

What is said respecting the amount of solar light received by a planet? What is the law of its intensity? Explain why the intensity of solar light is seven times greater at Mercury than at the earth? Illustrate the above law from the Figure. How does the apparent surface of the sun vary? How much larger would it appear at Mercury than it does at the earth?

conclusion, that the *mass* of the *sun exceeds* that of Mercury, 4,865,750 times, and that the *density* of the planet is $\frac{1}{8}$th *greater* than that of the earth.

442. ANCIENT OBSERVATIONS OF MERCURY. The earliest recorded observation of this planet was made 60 years after the death of Alexander the Great, on the 15th of November, 265 years before Christ. On the 19th of June, 118 A.D., the Chinese astronomers likewise observed Mercury to be near the Beehive, a cluster of stars in the constellation of Cancer, *retrograde* calculations by modern astronomers have shown, that on the evening of this day Mercury was distant from this group of stars *less than one degree.*

VENUS. ♀

443. DISTANCE AND PERIODIC TIME. We now come to Venus the second planet in order from the sun, and the most beautiful star that adorns the heavens. Her *mean distance* from the sun is 68,770,000 miles, and she revolves about this luminary in 224½ days, or more accurately 224 days 16h. 49m. 8sec.

444. APPARENT DIAMETER. The *apparent diameter* of Venus varies much more than that of Mercury, owing to the fact that the changes in the distance of this planet from the earth, are much greater. When Mercury is *nearest* to us, he is in round numbers but 58,000,000 miles distant, and when *most remote*, recedes from us only 132,000,000 miles; but Venus approaches as near to the earth as 27,000,000 miles, and then withdraws from it to the distance of 163,000,000 miles. This great change in the distance is shown, as in the case of the moon, by the *variation* in the planet's *apparent diameter*, for when it is at its *inferior conjunction* its diameter measures 70″, while at its *superior*, it is more than *seven times* smaller, being *less than* 10″.

445. REAL DIAMETER. This is not very precisely

State what is said respecting the mass and density of Mercury? What are the earliest ecorded observations of this planet? What is said respecting Venus? What is her *distance* from the sun? What her *periodic time?* Why does the apparent diameter of Venus vary more than that of Mercury? What is the greatest apparent diameter of Venus? What the least?

known, but according to the best observations, its length is about 7,900 miles, which is very nearly the same as that of the earth. No astronomer as yet has been able to determine by observation the exact difference between the *polar* and *equatorial* diameters of Venus. That a difference *exists* is evident from the rotation of the planet on its axis, but the *amount* of difference is unquestionably small.

446. ROTATION. The intense splendor of Venus invests every part of her disk with such a brilliant light that any variation in the surface of the orb for the most part escapes detection, since the valleys as well as the mountains, if such inequalities exist, are bathed in floods of light; and astronomers therefore speak doubtingly of *cloudy spots* upon the surface of the planet.

447. It is usually by directing their observations to *well defined spots*, that astronomers determine the period of the rotation of a planet upon its axis; the *absence* of such marks upon Venus, for a long time, rendered the time of her rotation a matter of uncertainty. One astronomer, Cassini, in 1667, fixed it at 23h. 16m. and another, Bianchini, in 1726, estimated it to be 24 *days* and 8 *hours*. At last Schroeter, the celebrated German astronomer, by directing his attention to a *mountain*, which he discovered near the *southern* horn of the planet, ascertained from *eight* observations, that this orb revolves on its axis in 23h. 21m. and 8sec. This result has been almost universally received, though it is not regarded by astronomers as exact beyond the possibility of an error.

448. According to the observations and calculations of the same astronomer, mountains exist on the surface of Venus, of the surprising height of *fifteen* or *twenty miles*, but no great confidence has been placed on these determinations, since the diameters of some of the small planets, as ascertained by Schroeter, are found to be

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What is the extent of the *real diameter* of Venus? Has any difference been observed between the *polar* and *equatorial* diameters? Must there be a difference? Why do we know scarcely anything respecting the *surface* of this planet? What is said in regard to the existence of spots? How do astronomers ascertain the *fact* and *time* of a planet's rotation? State by whom, and in what manner the rotation of Venus was discovered, and the period of the same determined? Is this period of Venus' rotation considered by astronomers as absolutely exact? What is said of the mountains of Venus?

much greater than those obtained by later astronomers with their improved and finely constructed instruments. It is therefore not improbable, that the want of accuracy and delicate refinements in his instruments led to the very great altitudes which Schroeter assigned to the mountains of Venus.

449. ORBIT—INCLINATION OF ITS PLANE TO THAT OF THE ECLIPTIC. Unlike that of Mercury the orbit of Venus is almost a *circle.* We have seen that the *mean solar distance* of Venus, is 68,770,000 of miles; if her orbit was a *circle* she would always be at the same distance from the sun, but the latter is a little out of the centre of the planet's orbit; so that when Venus is at her *aphelion* she is about 900,000 miles *farther* from the sun than when at her *perihelion.* This variation is much less than it is in the case of Mercury; whose *solar distances* at these points differ to the extent of 15,000,000 miles, (Art. 427.) The inclination of the plane of the orbit of Venus to that of the ecliptic is about 3° 23′ (more nearly 3° 23′ 29″.)

450. PHASES. In her revolution about the sun Venus, like Mercury, presents to our view similar *phases* to those of the moon. But since this planet is *nearly* twice as far from the sun as Mercury, and its *real diameter* is almost *three times* greater, these phenomena are more conspicuous, and can be observed for longer consecutive periods.

451. In a certain part of her orbit we behold this beautiful planet rising a little *before* the *sun,* when it is termed the *morning star.* It has then just passed its *inferior conjunction* and its *dark* side is turned *towards* the *earth,* like that of the moon when she is new. Venus now moves rapidly *westward* from the sun, rising every day earlier and earlier before this luminary, until she attains her greatest *western elongation* which is about 47° 15′. At this point of her orbit she rises between *three* and *four* hours before the sun, distinguished for her peerless splen-

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What is remarked respecting Schroeter's observations on the mountains of Venus? State what is said in regard to the orbit of Venus? What is the difference between Venus' *perihelion* and *aphelion* distances? How does this difference compare with Mercury's? What is the inclination of the plane of the orbit of Venus to that of the ecliptic? Why are the phases of Venus more conspicuous than those of Mercury?

dor among the stars that sparkle in the eastern sky She is now in her *first quarter*, only *one-half* of her enlightened hemisphere being visible through the telescope, to the inhabitants of our globe.

452. Still moving onward in her orbit Venus departs from her greatest western elongation towards her *superior conjunction*, and in so doing approaches the sun. She now rises *later* and *later* every day, her *illumined disk* becoming *gibbous*, like that of the moon in her *second* quarter, as is readily seen by the aid of the telescope. At length she arrives at her *superior conjunction*, when she is seen as the *moon* at the *full*, her bright disk being *nearly circular*.

453. A period of about *nine months* elapses from the time that Venus is first seen in the morning until she thus reaches her superior conjunction. Passing this place in her orbit the planet now appears on the other side of the sun (the eastern side,) rising *after* this luminary, and is consequently invisible to the naked eye, from the intense splendor of the solar light. But *rising* after the sun, the planet must necessarily *set* after it, and since the time of its setting grows later and later as it advances in its orbit, we at length see it beaming in the western sky soon after the solar orb has sunk beneath the horizon.

454. The planet is now the *evening star*, and by telescopic aid we perceive that its visible form is no longer *circular* but appears *gibbous* like the moon approaching her third quarter. Gradually Venus departs more and more from the sun, until she attains her greatest *eastern elongation*, at which point she is again seen through the telescope in the *shape* of a *half moon*. After reaching this limit, the planet returns towards the sun, resuming its crescent form. Having passed the sun it recommences its course as the *morning star*, going continually through the above series of changes. Fig. 70, is a representation of Venus as she appears when viewed through a telescope near her inferior conjunction.

455. SPLENDOR OF VENUS. Venus shines with the

Describe the phases in full?

FIG. 70.

TELESCOPIC APPEARANCE OF VENUS WHEN NEAR HER INFERIOR CONJUNCTION.

greatest brilliancy when her angular distance from the sun is a little less than 40°.[1] About once in *eight years*, under a favorable concurrence of circumstances, her splendor is unusually great. The brightness of the planet is then so intense that under a serene sky it can be seen even at noon day.

456. On account of the proximity of Venus to the sun, the *intensity* of the solar light is about *twice* as great on this planet as it is at the earth. For since their respective *distances* from the sun, are nearly as[2] 2 to 3, the degree of illumination which each receives will be expressed, according to the law of diffusion already stated (Art. 439,) by the numbers 4 and 9, which are nearly in the ratio of 1 to 2.

1. Venus does not appear brightest when she is *nearest* to the earth, because only a *small* portion of her illumined surface is then turned towards us. Neither is she most splendid when nearly *all her illuminated hemisphere* is presented to our view, because she is then *farthest* from us, and her apparent diameter is as small as possible. Her *place* of greatest brilliancy is therefore between these two positions, and is found, as stated in the text, to be a little less than 40° from the sun.

2. The earth's solar distance is about 95,000,000 miles. That of Venus nearly 68,000,000. The *latter* distance is therefore to the former in the ratio of about 2 to 3.

State what is said of the splendor of Venus? How much *greater* is the *intensity* of the solar light at Venus than at the earth? Why?

457. MASS—DENSITY. The *mass* is ascertained by various methods, and from the latest and most accurate investigations it appears, that the sun contains 401,839 times *more matter* than Venus. She has therefore a little *less* matter than the earth, since the mass of the sun is only 354,000 times greater than that of the earth. The *density* of *Venus* nearly equals the *density* of the earth, the former being to the *latter*, as 92 to 100.

458. ATMOSPHERE OF VENUS. Various observations have been made by astronomers upon this planet, which have led them to suspect that it is enveloped in an atmosphere. Beyond the true extremity of the horns when Venus appears crescent-shaped a *fine streak of pale blue light* has been not unfrequently seen, *projecting* over the *unilluminated* part of the orb, and which has been regarded as a *twilight*, i. e. *light reflected from an atmosphere*. Sir William Herschel noticed a *luminous border* around the planet, from which phenomenon he inferred that Venus possessed a dense atmosphere. The bright border being caused by the reflection of light from the particles of air composing the latter. Moreover, during a *transit* of Venus, various appearances occur which lead to the belief that an atmosphere surrounds this orb almost as dense as the atmosphere of the earth.

459. TRANSIT OF VENUS. This appellation is given, as in the case of Mercury to the passage of Venus across the sun's disk. A high importance is attached to this phenomenon by astronomers, since by means of it they are enabled to obtain with great accuracy the *parallax of the sun*, without which the distance of the earth from the sun could not be determined.[1] The *manner* in which the *parallax* is obtained, it is not difficult to understand, but the various mathematical processes which

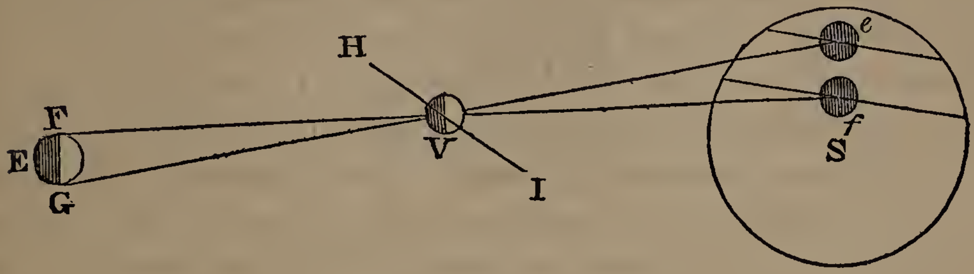
1. In order to ascertain the *solar distances* and the *magnitudes* of the planets, we have seen that the *distance* of the earth from the sun must be *first known*. It is also needed in order to determine the solar distances of some of the *fixed stars*, as will be shown in Part III. The accurate determination of the sun's parallax, is therefore of the utmost importance in astronomical researches.

What is the *mass* of Venus? What her *density*? What appearances have led astronomers to suspect that this planet is possessed of an atmosphere? What is said in regard to the transits of Venus?

conduct to the *result* are too complicated and abstruse to be admitted into an elementary work like this.

460. Let E, V, and S, Fig. 71, represent the relative positions of the earth, Venus, and the sun when a tran-

FIG. 71.



sit takes place, HVI a portion of the orbit of Venus, and FG, a diameter of the earth perpendicular to the ecliptic. If at the time of the transit two spectators were respectively placed at F and G, the diameter of the earth apart, the observer at F would see Venus in the direction FV, projected as a *dark spot* on the sun at *f*, and, at the same instant, the person at G would in like manner behold the planet in the direction GV, projected on the sun at *e*.

461. That such would be the case is evident from various familiar examples. Thus for instance if a tree is standing in the *middle* of a square field, and one person views it from the *south-east* corner of the lot, while a second beholds it from the *north-east* corner; the *first* sees the tree against the *north-west* portion of the sky, while the *second* observes it in the *south-west* quarter of the heavens.

462. Now Venus in the above position is nearly 68,000,000 miles from the *sun*, and about 27,000,000 miles from the earth, for the distance of Venus from the earth is equal to 95,000,000 miles *diminished* by 68,000,-000 miles, i.e. 27,000,000 miles. If we suppose *e* and *f* to be joined by a straight line, two *similar triangles* are formed; viz., FVG and *e*V*f*, whose sides are proportional. Considering FG as equal to 1 we then institute

Explain by the aid of Figure 71, in what manner the sun's horizontal parallax is obtained by observations on the transit of Venus?

the following proportion; to wit, GV (27,000,000 miles) : V*e* (68,000,000 miles) : : FG (1) : *ef*. By the rule of three *ef* is found to be nearly equal to $2\frac{1}{2}$, that is, it is *two and a half times greater* than FG.[1]

463. If therefore the line FG (the *earth's diameter*) were placed upon the sun, it would occupy about $\frac{2}{5}$ths of the extent of *ef*, and the angular measurements of these two lines, as viewed from the earth would be nearly in the same *ratio*. But the *sun's horizontal parallax* (Art. 94,) is the *angle under which the earth's radius is seen at the distance of the sun from the earth*, it must therefore be *equal to $\frac{1}{5}$th of the angle* which the line *ef* measures at the distance of the earth from the sun.[2] The *value* of this angle can be ascertained when *each observer* notes at his station the *exact time* occupied by the planet in *crossing the disk of the sun*, and *one-fifth* of this value is the *sun's horizontal parallax*.

464. The last transit of Venus, from the observations upon which the value of the sun's horizontal parallax as now received was obtained, took place in 1769. Extensive preparations were made in various quarters of the world for ensuring the most available and accurate observations. Capt. Cooke was sent by the British government to Tahiti, and many other European powers dispatched their ablest astronomers to places most eligible for this purpose. The *farther apart* the observers are, the *greater* will be the displacement of Venus on the solar disk, and the greater the difference in the *duration* of the *respective transits*; but this difference is small at the best, and therefore astronomical stations are sought, which are widely separated from each other. On this account the observations which were taken at Tahiti, in the South Seas, and at Cape Wardlaus in Lapland, were of great value.

1. The solar distances of Venus and the Earth are here employed for the sake of convenience. The *ratio* between GV and V*e* can be found without them, by observations upon Venus at her greatest elongations.

2. The *radius* of the earth which is the *half* of FG, must evidently equal $\frac{1}{5}$th of *ef*.

When did the last transit of Venus occur? What preparations were then made by the various governments of Europe? What observations were of great use? Why?

465. The result obtained on this occasion by the combined efforts of scientific men, gave for the sun's parallax 8″.6 more nearly 8″.5776. This is considered certain within a small fraction of a second, and separate investigations by Prof. Encke, and M. de Ferrer, have led to exactly the same value.

466. The transits of Venus for a long time will occur early in the months of June and December; since the planet passes her nodes in the beginning of these months, and the *motion* of the nodes along the ecliptic is extremely small. They are however phenomena of rare occurrence, happening at intervals of about *eight* and *one hundred and thirteen years.* The next transit takes place December the 8th, 1874; another December 6th, 1882. None happens during the 20th century, the next occurring on the 7th of June, 2004, A. D.

THE EARTH. ⊕

467. The next planet is the Earth. This with its attendant *moon* we have already discussed and therefore pass on to the *superior planets.*

SUPERIOR PLANETS.

468. These celestial bodies are more distant from the sun than the earth is, and their *orbits* consequently *encircle* that of the earth. They are in *superior conjunction* when the *sun* is directly *between them* and *earth*, and in *opposition* when the earth is *directly between* them and the *sun.* As they can never come between the earth and the sun, it is of course impossible that they should have any inferior conjunction; on this account they are *not subject* to *phases* like those of Mercury and Venus. Moreover they are seen at all angular distances from the sun, from 0° to 180°. In these *three respects*, as viewed from the earth, they differ from the inferior planets. The next planet in order is Mars.

What is the value of the sun's horizontal parallax as deduced from these observations? Is this perfectly exact? Have other investigations been made? In what months of the year will the transits of Venus occur for a long while? Why? Are these phenomena frequent? When will the next transit take place? What is the next planet in order? What is said of it? What is said respecting the superior planets? Have they any inferior conjunction? State the *three particulars* in which they differ from the inferior planets as viewed from the earth? What is the name of the superior planet next in order?

MARS. ♂

469. Distance—Orbit—Inclination of the plane of the orbit. This planet is situated at the average distance of about 145,205,000 miles from the sun, but as the orbit in which it moves is an ellipse that deviates very much from a circle, the difference between its *perihelion* and *aphelion* distances is very considerable. The former amounting to 158,754,000 miles, and the latter to 131,656,000 miles, their difference being 27,098,000. miles. The inclination of the plane of the orbit of Mars to that of the ecliptic is about 1° 53′.

470. Periodic Time. The period of time occupied by Mars in making one revolution about the sun, is according to the best computation, 686 days 23h. 30m. 41sec.

471. Real and Apparent Diameter. The *real diameter* of Mars is about 4,500 miles, but his *apparent diameter* is subject to great variations; for at the time of his *superior conjunction* when he is *most remote* from us, his apparent diameter measures only a little more than 4″; but when *nearest* to us, and in *opposition* its angular extent exceeds 30″.

472. On this account, Mars when nearest to us shines with great splendor, and rising about sunset moves along the sky a conspicuous object throughout the night, but when most remote from the earth he appears like a star of ordinary size. The cause of these great changes is readily perceived, when we consider, that in as much as the orbit of Mars includes that of the earth, his distance from the earth at *superior conjunction*, equals his own distance from the sun *increased* by that of the earth's solar distance, and at *opposition* it is only equal to the *difference* of these distances. Stating the same in figures, the distance of Mars from the earth at superior conjunction, amounts in round numbers to 145,000,000 miles, *added* to 95,000,000 miles, or 240,000,000 miles, while at opposition it is equal to 145,000,000 miles *diminished* by

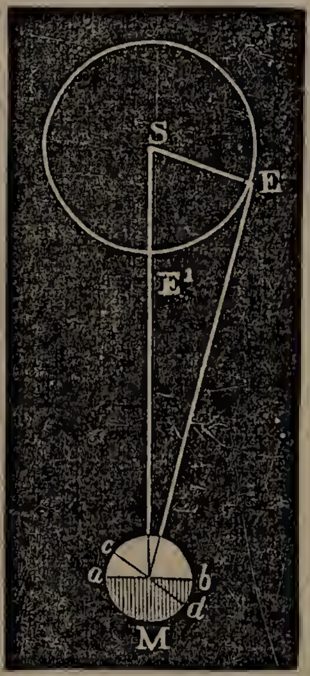
What is the solar distance of Mars? What is said of its orbit? What is the inclination of its plane to that of the ecliptic? What is his *periodic time?* What is the length of the real diameter of Mars? What is said respecting the changes in his *apparent diameter?* When is it *greatest?* When *least?* What is said of the changes in the splendor of Mars? Explain the cause of these variations?

95,000,000 miles or 50,000,000 miles. A variation in distance so extensive as this, must of course give rise to corresponding changes in the *apparent size* and *brilliancy* of the planet.

473. PHASES. Although Mars never exhibits *phases* like those of Mercury and Venus, his illuminated surface is nevertheless subject to slight fluctuations in form. At the time of *opposition* the planet is exactly *circular* but in other positions is *oval*, owing to the circumstance that we then view it out of the line *joining the centre of the planet* and the *sun*, and therefore lose sight of a part of the surface that is illumined by the solar rays.

474. This point is illustrated by Fig. 72, where S represents the sun, the circle around it the orbit of the

FIG. 72.



PHASES OF MARS.

earth, E and E¹ two positions of the earth, and M, Mars. Now since *half of the surface* of Mars is illumined by the sun, the *boundary* of the *visible* portion, as seen from the sun, may be represented by the *line ab* drawn *perpendicular* to the line joining the *centres* of the *sun* and *Mars*. To a spectator at S the shape of Mars would be

Does this planet exhibit phases like those of the inferior planets? To what changes is its visible surface subject? Explain the cause? Illustrate from Figure.

a *circle*, and it would be the same to a person on the earth, when the earth is at E[1], Mars being in *opposition*.

475. But when the earth is at E, a part of the *enlightened hemisphere* of Mars is *invisible* to a spectator at E; for that which is included between the lines *ab* and *cd* has passed out of view and he can see no farther than *c* in the direction of *a*. Accordingly when the sun, the earth, and Mars are situated as in the figure, the planet as seen from the earth will appear of an *oval* shape.

476. The form of the visible surface of Mars becomes *more* and *more oval* from *opposition* to *quadrature*[1]; in which position the planet resembles the moon a day or two before her *third quarter*, and accordingly is generally seen *gibbous*; but even then, the illuminated surface is never less than *seven-eighths of a circle*.

477. Physical Aspect — Atmosphere. When viewed through a telescope of adequate power, the outlines of *continents* and *seas* are revealed on the surface of Mars, while near *the poles*, at the planet's latitude of 75° or 80°, *white spots* are discerned, which, from their increase and decrease with the change of its seasons, have been regarded by Sir Wm. Herschel as *masses of ice and snow* that accumulate during the winter of Mars, and diminish in the summer. The *continents* appear of a dull *red hue* while the seas possess a *greenish* [2]*tinge*. The *ruddy hue* of the planet, by which it is easily distinguished from other heavenly bodies, is attributed by Sir John Herschel to the prevailing color of the land.

478. It was formerly supposed that the red hue of Mars was owing to a very *dense atmosphere*, but the late observations of astronomers show that there exists no good ground for this belief; the atmosphere appearing to be only moderately dense and not very extensive.

1. For the meaning of *quadrature*, see Art. 272.

2. The greenish tinge is supposed by Herschel to be the effect of contrast. For example if we gaze steadily upon a *red wafer* for a considerable time and then look upon a white object as a piece of paper, the *latter* will appear of a *blueish green* hue.

What variations take place from opposition and quadrature? What is the phase of Mars at quadrature? What portion of a circle does the illuminated surface measure when *least*? Describe the physical aspects of Mars? What is said respecting the existence of an atmosphere?

479. ROTATION. The rotation of this planet on its axis has been determined by observing the spots upon its surface. The *time* of rotation was estimated by Sir Wm. Herschel, at 24h. 39m. 21.67sec., but Prof. Mädler from recent observations reduced this time to 24h. 37m. 20sec. which may be regarded as the length of a day on the planet Mars.

480. INCLINATION OF THE AXIS. Observations upon the spots have shown that the axis about which Mars rotates is inclined to the plane of his orbit at an angle of 61° 18′. This quantity is very nearly *equal* to the inclination of the earth's axis to the plane of its orbit, and as the *seasons* depend in a measure upon this inclination, those of Mars are probably somewhat like our own.

481. ELLIPTICITY. The *rotation* of Mars necessarily produces a difference in the length of the *polar* and *equatorial diameters*, the planet being *flattened* at the *poles* and *swelled* out at the *equator*. This compression was, until lately considered to be very great, the ratio of the polar to the equatorial diameter being according to Sir Willam Herschel, as 15 to 16; so that if the length of the *equatorial* diameter of this planet is reckoned at 4,500 miles, that of its *polar* diameter is only 4,219 miles; the *latter* being thus 281 miles *shorter* than the former.

482. But according to Mr. J. R. Hind, an extensive series of very accurate observations, recently taken with the best instruments, make the compression much less, the ratio of the diameters being as 51 to 50, which result is regarded as being much nearer the truth than the estimate of Herschel. According to this computation the difference between the polar and equatorial diameters of Mars, is only about 88 miles.

483. DENSITY—MASS. The *density* of Mars is very nearly equal to that of the earth, the former being to the latter as 95 to 100. The *quantity* of matter contained in this planet as estimated by Burckhardt is *seven times less* than that contained in our globe.

How has the rotation of Mars been determined? What is its period? What is the inclination of the *axis of rotation* to the plane of the orbit of Mars? What is observed in regard to the seasons of this planet? What is said respecting the ellipticity of Mars? What is its extent according to Sir William Herschel? What according to Mr. J. R Hind? What is the *density* of Mars? The *mass*?

484. Intensity of solar light. The *relative intensities* of the solar light at Mars and at the earth, as found by the rule already given (Art. 439,) are represented by the numbers 43 and 100. To illustrate, if on a given surface the earth receives 100 solar rays, Mars receives on the *same* extent of surface only 43 rays.

485. Fig. 73, represents Mars as viewed by the accomplished astronomer Sir John Herschel, in his 20 feet

FIG 73.

MARS AS SEEN BY SIR JOHN HERSCHEL.

telescope, on the 16th of August, 1830. It shows the planet in its *gibbous* state, with the outlines of its *continents* and *seas;* while *one* of the *white spots* which are situated near its poles is distinctly discernable on its surface.

THE ASTEROIDS.

486. The astronomer Kepler, 250 years ago, noticed a tendency to a *regular progression* in the distances of the planets from the sun, as far as Mars. *Twice* the distance of Mercury from the sun, is nearly the *distance of Venus, three times* that of Mercury is about the *distance of the*

What the relative intensities of the solar light at the *earth* and at Mars? What does Fig. 73, represent? What did Kepler remark in regard to the solar distances of the planets?

earth, and *four times* the distance of Mercury gives almost exactly the *distance of Mars*. But in order to represent the distance of Jupiter, between which orb and Mars no planet in the time of Kepler was known to exist, the distance of Mercury must be multiplied *not by* 5 *but by* 13.

487. The law appeared here to be *broken*, and an immense interval of 350,000,000 miles, extending between Mars and Jupiter, to be unoccupied by a single planetary body. Kepler imagined that in order to preserve the harmony of distance *another planet* existed in this vast space, which had hitherto eluded the searching gaze of astronomers.

488. For two centuries nothing was done to verify or overthrow this hypothesis of Kepler; but when in 1781 Uranus was discovered by Sir Wm. Herschel, an impulse was given to astronomical investigations, and an association of astronomers commenced a systematic search for this supposed planet, whose probable distance they determined by the law of Bode. Ere long instead of *one*, *four small planets* were discovered to which were assigned the names of Ceres, Pallas, Juno, and Vesta.

489. Nearly 50 years more elapsed when the search was renewed in the same region of space, and the discovery of *fifty-three additional asteroids* has rewarded the labors of the astronomer.

490. *Two circumstances* enable an observer to distinguish a *planet* from a *fixed star*. *First*, the latter class of heavenly bodies as ordinarily viewed, always keep at the *same distance* from each other. *Secondly*, how much soever a *fixed star* is magnified, it still appears as a *mere point of light* on account of its immense distance from us, while a *planet* has a *round disk* like the moon. When therefore an astronomer, watching a star from night to night, beholds it *gradually approaching* the assemblage of fixed stars, that are situated on one side of it, and *receding* from those on the other, he pronoun-

Where was this law broken? What did this fact lead him to think? Was anything done by the astronomers, who immediately succeeded Kepler to confirm or overthrow his hypothesis? When was a new impulse given to astronomical research, and why? What was then done by astronomers? What success has attended this search for planets? How can a *planet* be distinguished from a *fixed star*?

ces it at once a planet; and if he is also able to discern a *round well-defined disk* he possesses an additional proof of the planetary nature of the body.

491. The discovery of planets has been very much facilitated by the use of *celestial* maps and *charts*, where the *stars* are now laid down with such precision, that if one, which has been regarded as *fixed*, is really a *planet*, its departure from the place assigned it on the map is very soon detected, and its true character known.

492. We shall now proceed to speak briefly of the several *asteroids*, taking them in the *order of their discovery.*

CERES. ⚳

493. On the 1st of January, 1801, Prof. Piazzi, of Palermo, while searching for a star which was mapped down on a star-chart, but which he could not find in the heavens, observed an object near the place of the *missing* orb, shining like a star of the *eighth magnitude*[1] and which he took at first to be a *comet*, but which proved to be a *planet.* It was soon afterwards lost sight of on account of its nearness to the sun, but on the 1st of January, 1802, it was re-discovered by Dr. Olbers, of Bremen. In March, 1802, a friend of Prof. Bode, beheld the planet with the *naked eye*, though it generally requires the aid of a telescope in order to be discerned, as it is just beyond the limit of unassisted vision.

494. The smallness of Ceres has precluded any very exact measurements of her size. According to Sir Wm. Herschel's observations she is only 163 miles in diame-

1. *Eighth magnitude.* The stars are divided into *classes* according to their *apparent brightness.* The *brightest* are termed stars of the *first magnitude.* Those which are nearly as brilliant, but whose splendor is yet perceptibly less, belong to the *second magnitude.* This classification is extended down to the *sixteenth* magnitude. The *sixth or seventh* magnitudes includes the *smallest stars visible* to the *naked eye* under the most favorable circumstances. All the stars below these magnitudes require a telescope to render them discernible. In Part III. this subject will be more fully discussed.

What has facilitated the discovery of planets? Of what bodies are we now to speak? By whom was Ceres discovered? When and under what circumstances? How large does she appear?

ter, and this determination is regarded as the most accurate which has been attained. Her *mean distance from the sun* is 262,764,110 miles, she *revolves* around it in about 1,680 days, and the *inclination* of the plane of her orbit to that of the ecliptic is little more than 10° 37′. This planet shines with a *pale reddish light*, and a slight haziness that envelopes it has led some to think, that it is possessed of an atmosphere. The symbol of Ceres, the goddess of agriculture, is the *sickle.*

PALLAS. ⚴

495. While Dr. Olbers on the 28th of March, 1802, was examining various groups of stars, which lay near the path of the planet Ceres, he found a star in a position where he was certain none was visible during the two preceding months. The observations of the same and the succeeding evening showed that it evidently *moved among the* fixed stars—a *new planet* was found, to which the name of *Pallas* was given, and the *lance head* indicative of the character of the goddess was selected as its symbol.

496. Pallas shines as a star of the *seventh* magnitude with a fine *yellowish* light. A haziness, less dense than that which belongs to Ceres, has been noticed by some astronomers encircling the planet, and has led them to conjecture that Pallas is also surrounded by an atmosphere.

497. The most reliable measurement of the size of this planet is that taken by Dr. Lamont, of Munich, who makes its diameter to be 670 miles. Its *mean distance* from the sun is 263,186,670 miles, its *periodic time* 1,684 days, and the *inclination* of the plane of its orbit to that of the ecliptic 34° 37′ 20″.

JUNO. ⚵

498. This asteroid was discovered by Prof. Harding,

What is her *diameter?* *Mean solar distance* and *periodic* time? What is the *inclination* of the plane of her orbit to that of the ecliptic? What is her color? Has she an atmosphere? What is her symbol? Who discovered Pallas, and in what manner? At what time? What is her symbol? How large does Pallas appear? Has she an atmosphere? What is her *diameter?* *Mean solar distance* and *periodic time?* What is the *inclination* of the plane of her orbit?

of Lilienthal, on the 1st of September, 1804, while forming charts of small stars lying in the paths of Ceres and Pallas. At ten o'clock on the evening of this day he observed a star near several others in the constellation of the Fishes, which on the evening of the 4th had *changed its place*, and continued to do so night after night. The name of Juno was given to this planet, and as *Juno* was queen of Olympus, a *sceptre crowned* by a *star* was chosen as the symbol of the asteroid.

499. This planet appears as a *reddish* star of the *eighth* magnitude. Its *mean distance* from the sun is 253,524,410 miles, its period of *revolution* 1,592 days, and the *inclination* of the plane of its orbit to that of the ecliptic is 13° 3′ 17″.

VESTA. ⚶

500. After the discovery of Pallas, Dr. Olbers noticed that the orbits of Pallas and Ceres approached very near each other at *one of the nodes* of Pallas, a circumstance which led him to think that these two bodies were but *fragments* of a *larger planet*, which once existed between Mars and Jupiter, at the mean solar distance of Ceres and Pallas, and was *shivered* to pieces by some tremendous convulsion. Other fragments yet undiscovered he believed were still moving in space, and although the *planes* of their *orbits* might be *differently inclined* to that of the ecliptic, yet as they all had the *same* origin he supposed there must be *two points* in the orbit of each *through which* the rest at some time or other must necessarily pass. These *two points* are the *places* where the planes of the orbits of these fragments intersect one another.

501. By watching these points he thought it not impossible that some of the flying fragments might be detected; it was in *one* of these that Juno was found, and other planets might reward a systematic search. The

By whom was Juno discovered? When? Under what circumstances? What is her symbol? Her color? How large does she appear? What is her *mean solar distance*, *periodic* time and the *inclination* of the plane of her orbit? After the discovery of Pallas what did Dr. Olbers observe? What hypothesis did he found upon this circumstance? State why he thought it possible to discover the other fragments and the method he adopted for this purpose?

two points where the orbits of the three newly discovered planets mutually intersected, were in the constellations of the Virgin and the Whale, and in *one* of these two regions the supposed convulsion must have happened, and through this place he conceived the fragments must still pass.

502. Every month the astronomer examined the small stars in one or the other of these constellations. On the 29th of March, 1807, he beheld a star of the *sixth* or *seventh* magnitude in the constellation of the Virgin at a place where previous examination had shown that no star was visible. Upon the same evening he found that the object was really *in motion*, and continuing his observations until the 2nd of April, he became satisfied that this new object was in fact *another planet.* The name of *Vesta* was assigned it, and a *flame burning upon an altar*, in allusion to the peculiar rites of the goddess is its appropriate emblem.

503. Vesta is a small planet having a *diameter* of only 295 miles, yet when in opposition to the sun she appears the brightest of all the asteroids, and can be discerned without a telescope by a person of good eye-sight. A difference of opinion exists respecting the color of Vesta; some considering the planet to be of a *ruddy tinge*, others perfectly *white*, while to Mr. J. R. Hind, who has repeatedly examined it with glasses of various magnifying powers, it has always appeared of *a pale yellowish hue.*

504. The *distance* of Vesta from the sun is 224,327,205 miles, and the *period of her revolution* 1,325 days. The plane of her orbit is *inclined* to that of the ecliptic 7° 8′ 25″.

ASTREA. ♎

505. Dr. Olbers continued his systematic search among the small stars in the constellations of the Virgin and the Whale, with unwearied assiduity until the year

When did Dr. Olbers discover the fourth asteroid? State the circumstances attending the discovery? What name was assigned it? What is the size of Vesta? What is her *diameter*? Splendor? Color? Her *mean solar distance*, *periodic time*, *inclination* of her orbit? Did Dr. Olbers detect any other planet?

1816; but no new planet was detected, and he then abandoned his examination, regarding it as useless to continue it any longer. But all the members of this remarkable group of planetary bodies had not yet been discovered.

506. On the 8th of December, 1845, while Mr. Hencke, of Driessen, was engaged in his astronomical labors he perceived in the constellation of *Taurus* a *small star*, that was not mapped down in an excellent star-chart which he was then comparing with the heavens. He at once concluded that it was a new planet, and ere three weeks had elapsed its *motion* among the stars was fully established. At the request of the discoverer, the renowned astronomer Encke named the planet, which he called *Astrea*.

507. Astrea shines with a faint *light*. She can not be seen without a good telescope, for even under the most favorable circumstances her brightness scarcely exceeds that of a star of the *ninth magnitude*. This planet is *distant* 244,767,500 miles from the sun, and *revolves* about it in 1,511 days. The *inclination* of the plane of its orbit to the ecliptic, being 5° 19′ 23″. Astrea being the goddess of justice, the *equally poised scales* has been adopted as the sign of the planet.

HEBE. ⚵

508. Mr. Hencke still continuing to compare his star-maps with the heavens, found on the 1st of July, 1847, a minute star neither marked down on his star-chart, nor seen by himself, on a previous examination of the heavens, in the place where he now saw it. Repeating his observations at midnight, on the 3d of July, he found it had *changed its place among the stars*; he therefore pronounced it a *planet*, and before long it was recognized as such at all the principal observatories in Europe.

509. The new asteroid was called *Hebe*, and a *cup*, symbolical of the office of this divinity, was adopted as

· How long did he continue his search? Why did he relinquish it? State *when*, by *whom*, and under what circumstances Astrea was discovered? Describe Astrea? What is her *solar distance*, *periodic time*, and the *inclination* of her orbit? What is her sign? State by whom, *how*, and when Hebe was discovered?

its sign. The *inclination* of the orbit of Hebe is 14° 46′ 32″, her *distance* from the sun 230,414,710 miles, and the *period of* her revolution 1,380 days. A *ruddy hue* tinges the planet.

IRIS.

510. The system of comparing star-maps with the heavens was at this time pursued by other astronomers as well as by Mr. Hencke, and with like results. In this field of research Mr. J. Russell Hind, of London, has especially distinguished himself. In November, 1846, he commenced a close and extensive examination of the heavens, with the aid of star-charts and maps, but no immediate discovery of any planetary body rewarded his labors. After *nine months* of patient observation, success began to crown his efforts. On the 13th of August, 1847, he noticed a body like a star of the *eighth* magnitude, at a place where no star had been seen before. He watched it closely, and in *an hour it had changed its place* so much as to leave no doubt of its being a *planet.* Within a short time it was seen from the principal observatories on the Continent.

511. The *new asteroid* received the name of *Iris*, and in allusion to the nature of the goddess a *semi-circle* representing *a rainbow* with a *star* in the centre, and a line joining the extremities forms the symbol of the planet. Iris *revolves* about the sun in 1,346 days, at the *mean distance* 226,683,965 miles. Her orbit is *inclined* to the ecliptic 5° 28′ 16″. The *size* of the planet has not yet been ascertained.

FLORA.

512. A little more than two months elapsed after the discovery of Iris, when, pursuing the same method of research, Mr. Hind had the pleasure of discovering another planetary body. On the 18th of October, 1847,

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Give a full account of this asteroid? What is said respecting Mr. J. Russell Hind? When did he first discover a planet, and in what manner? What name was given to this new body? What is the *symbol* of Iris? What her *periodic time, solar distance*, and what the *inclination* of her orbit? Do we know any thing respecting the size of this planet?

at 11 o'clock in the evening, he noticed a *small bright object* like a star of the *eighth* or *ninth* magnitude, in the constellation of Orion, at a point where no object had been previously observed. The occurrence of clouds prevented any further observation until 3 o'clock, when the change of place during the *four* hours that had elapsed since it was first beheld, was so marked as to decide at once the planetary nature of the body.

513. The name of *Flora* was given to the planet, and a *flower* called the *rose of England* was selected as its emblem. The light of Flora is of a *reddish hue*, her *mean distance* from the sun, is 209,131,670 miles, and her *periodic time* 1,193 days. The *inclination* of the plane of her orbit to the ecliptic is 5° 53′ 03″, a little more than that of Iris. The *diameter* of the planet has not yet been ascertained.

METIS.

514. On the 25th of April, 1848, Mr. Graham, of Markree Castle in Ireland, detected a star of the *tenth* magnitude in a position where none had been noticed before. On the following evening it had *changed its position* so decidedly as to establish at once its nature as a planet. It received the name of *Metis*, and a *star with an eye* constitutes its sign.

515. Metis shines with a fainter light than Flora and Iris, and requires a good telescope to see her well. The *magnitude* of this asteroid has not yet been determined. It *revolves* about the sun in 1,346 days, at the *mean distance* of 226,644,350 miles, its orbit having an *inclination* to the plane of the ecliptic of 5° 35′ 55″.

HYGEIA. 10

516. Scarcely a year elapsed after the discovery of Metis before another member was added to this numerous cluster of planets, for on the 12th of April, 1849,

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Relate all that is said respecting Flora? When and by whom was Metis discovered? What is said respecting it? What is the *magnitude* of this asteroid, *periodic time*, *solar distance*, and what the *inclination* of her orbit?

Dr. Gasparis, the assistant astronomer at the Royal Observatory at Naples, observed a star of between the *ninth* and *tenth magnitude*, in a situation where no star had been visible at any previous examination. The obscurity of the sky prevented any further observations until the evening of the 14th, when the object had perceptibly *changed its place*, thus proving itself to be a planet. It has received the appellation of *Hygeia.*

517. No measurements have been made of the *diameter* of the planet, its *distance* from the sun is about 299,190,435 miles, and its *periodic time* is nearly 2,041 days. The *inclination* of its orbit to the ecliptic is estimated at 3° 47′ 11″.

518. The *symbol* of Hygeia, is a circle inclosing the figures denoting the number of the asteroid in the order of discovery[1].

PARTHENOPE (11)

519. On the 11th of May, 1850, Dr. Gasparis succeeded in discovering another planetary body; for on the evening of this day he observed a bright object shining like a star of the *ninth* magnitude which perceptibly changed its position among the fixed stars. Upon the news of the discovery astronomers were on the alert, and before the end of the month the asteroid was seen from many of the European observatories. To identify it with the place of its discovery, the new planet was called *Parthenope*, a nymph of mythology after whom the city of Naples was formerly called. The *periodic* time of Parthenope is estimated by astronomers to be 1,403 days, her *mean solar distance* 232,995,860 miles, and the *inclination* of her orbit 4° 36′ 54″.

1. This system of symbols was proposed by eminent astronomers, after a large number of the asteroids had been discovered, and there was every reason for believing, from the previous success in this field of research, that many others were yet to be found.

When, by whom, and under what circumstances was the next planet detected? What name was given it? What is its *diameter*, *solar distance*, and *periodic* time? What is the *inclination* of the orbit of Hygeia? What is the symbol of Hygeia? State what is said in the note in respect to symbols? When did Dr. Gasparis discover another planet? How was the discovery made? Was the new asteroid soon identified? What name was assigned it? Why? What is known respecting the *periodic* time, *solar distance*, and the *inclination* of the orbit of Parthenope?

VICTORIA, OR CLIO

520. On the 13th of September, 1850, Mr. J. R. Hind, the discoverer of Flora and Iris, observed in the constellation of the Winged Horse (Pegasus,) a star of the *eighth* magnitude, near another which had frequently before been examined without the presence of its bright attendant being noticed. A peculiar appearance which it presented satisfied the observer that a planet was in sight, and that it was a *new one*, for all the *known* members of the asteroid group were then in different parts of the heavens. In *less than an hour* the bright object had *moved visibly to the west*, at such a rate as to leave no doubt that it was another planet belonging to the group existing between Mars and Jupiter.

521. The names of *Clio* and *Victoria* have been proposed by Mr. Hind from whence to select an appellation for the planet. The discoverer and the principal European astronomers have chosen the former, while their American brethren prefer the latter. The symbol of Victoria is a *star surmounted* by a *laurel branch.*

522. This asteroid *revolves* about the sun in 1,301 days at the *mean distance* of 221,617,045 miles, the *inclination* of her orbit being 8° 23′ 7″. When beaming with her greatest brilliancy, Victoria resembles a *bluish star* of the *eighth* magnitude, but at other times, when her distance from our globe is much increased, she shines with scarcely more light than a star of the *eleventh* magnitude. Nothing is known respecting her actual size.

EGERIA. (13)

523. On the 2nd of November, 1850, Dr. Gasparis, the discoverer of Hygeia and Parthenope, detected the thirteenth member of the asteroidal group in the *constellation* of the Whale, (*Cetus*,) the region where Olbers had made his examinations. This planet is much fainter than

State *when* and by *whom* Victoria or Clio was discovered? Give an account of this discovery? Which name is adopted in Europe? Which in America? What is the symbol of Victoria? *Periodic time? Solar distance? Inclination of her orbit?* What is said respecting her brightness and appearance? Do we know any thing in regard to her real *magnitude*? When was Egeria discovered? By whom?

Victoria, and shines as a star of the *ninth* magnitude. The name of *Egeria* has been given to this body. The *period* of its revolution about the sun is 1,510 days, its *mean solar* distance 244,684,375 miles and the *inclination* of its orbit to the *ecliptic* 16° 33′ 7″.

IRENE.

524. Another asteroid was discovered by Mr. J. R. Hind in the constellation of the Scorpion on the 19th of May, 1851, and *four days* afterwards by Dr. Gasparis of Naples. It appeared to the discoverer as a *blue star* of between the *eighth* and *ninth* magnitude, and seemed to be invested with a dim *hazy envelope like an atmosphere*, which was not discerned around those stars which shone with equal brightness. Within *half an hour* of the time when it was first seen its planetary nature was established beyond dispute.

525. The planet received the name of *Irene*, in allusion to the general peace then prevailing throughout Europe. The emblem of this asteroid is a *dove* with an *olive branch* and a *star* on its head. According to the most reliable calculations the solar *distance* of Irene is 245,989,960 miles, and her *periodic time* 4,15 years, or 1,522 days. The *inclination* of her orbit to the ecliptic is estimated at 9° 5′ 33″.

EUNOMIA. 15

526. The labors of Dr. Gasparis were still further crowned with success, for on the night of the 29th of July, 1851, another small planet was discovered by this astronomer, shining as a star of the *ninth* magnitude. Dr. Gasparis gave this planet the name of *Eunomia*, who according to the classic poets was a sister of Irene. Eunomia *revolves* about the sun in a period of 1,570

What is her *magnitude*, *periodic time*, *solar distance*, and the *inclination of her orbit*? State when, by whom, and under what circumstances Irene was discovered? Why so called? What is her symbol? What is her *solar distance*, *periodic* time, and the *inclination* of her orbit? Who discovered Eunomia, and when? What is her *magnitude*? What her *periodic* time?

days, and at the *distance* of 251,197,100 miles. The *inclination* of her orbit is 11° 43′ 50″.

527. The rest of the newly discovered planets have been found so rapidly that at present very little is known respecting them, except their *elements*[1], and even these are not yet ascertained with perfect exactness.

PSYCHE. (16)

528. This asteroid also was discovered by Dr. Gasparis on the 17th of March, 1852. It appears like a star of between the *tenth* and *eleventh* magnitude. The *solar distance* of *Psyche* is 277,661,440 miles, and the *inclination* of her orbit 3° 3′ 37″. Her *periodic time* is 1,825 days.

THETIS. (17)

529. Thetis was discovered by Mr. Luther at the observatory of Bilk near Düsseldorf, on the 19th of April, 1852. The light of this planet is very faint. Its *distance from the sun* is 235,002,450 miles, the *inclination* of the plane of its orbit to that of the ecliptic, 5° 42′ 32″, and its *periodic time* 1,421 days.

MELPOMENE. (18)

530. Mr. J. R. Hind discovered on the 24th of June, 1852, the eighteenth asteroid to which the above name was given. It appeared like a star of the *ninth* magnitude, shining with a steady *yellowish light*. The *solar distance* of *Melpomene* is 218,125,700 miles, the *inclination* of her orbit 10° 10′ 38″, and her *periodic time* 1,271 days.

1. The *elements* of a planet are certain particulars respecting it, which are necessary to be known, in order to ascertain its position in the heavens at any time. They are,

1. *The mean longitude of the planet at any particular date.*
2. *Longitude of the perihelion.*
3. *Longitude of the nodes.*
4. *Eccentricity of the orbit.*
5. *Inclination of the plane of the orbit to that of the ecliptic.*
6. *The periodic time of the planet.*
7. *Its mean distance from the sun.*

Solar distance, and the *inclination* of her orbit? What is said respecting the rest of the newly discovered planets? Give an account of Psyche, Thetis, Melpomene.

FORTUNA. (19)

531. On the 22d of August, 1852, Mr. J. R. Hind discovered still another asteroid, shining like a star of the *ninth* magnitude. It has received the name of *Fortuna*, and is *distant* from the sun 231,929,960 miles. The *inclination* of her orbit is 1° 33′ 18″, and her *periodic time* 1,393 days.

MASSALIA. (20)

532. *Massalia* was discovered by Dr. Gasparis of Naples on the 19th of September, 1852. The *inclination* of the orbit of this asteroid is 0° 50′ 16″, its *distance* from the sun 228,891,670 miles, and its *periodic time* 1,366 days.

LUTETIA. (21)

533. This planetary body was found by Mr. Goldschmidt, of Paris, on the 15th of November, 1852. It resembles a star of between the *ninth* and *tenth* magnitude. Its *solar distance* is 231,365,945 miles, and its *inclination* 3° 19′ 50″. Its *periodic time* is 1,388 days.

CALLIOPE. (22)

534. *Calliope* was discovered by Mr. J. R. Hind, on the 16th of November, 1852. This asteroid in brightness ranks between the *ninth* and *tenth* magnitude, the *inclination* of its orbit is 14° 20′ 13″, its *solar distance* 237,080,005 miles, and its *periodic time* 1,440 days.

THALIA. (23)

535. The *twenty-third* asteroid was discovered by Mr. J. R. Hind on the 15th of December, 1852. It resembles a star of between the *tenth* and *eleventh* magnitudes, shining with a *pale blue light*. The name assigned this planet is *Thalia*. The *distance* of Thalia from the sun is 249,738,280 miles. The *inclination* of her orbit is 10° 19′ 27″, and her *periodic time* 1,557 days.

Give an account of Fortuna, Massalia, Lutetia, Calliope, Thalia.

THEMIS. (24)

536. *Themis* was discovered by Dr. Gasparis of Naples, on the 5th of April, 1853. This planet ranks in brightness with a star of the *twelfth* magnitude. Its *inclination* is 0° 53′ 47″, and its *solar distance* is 299,-244,965 miles. Its *periodic time* is 2,042 days.

PHOCŒA. (25)

537. On the 6th of April, 1853, Mr. Chacornac of Marseilles found a new planet which he called *Phocœa.* It is of a *blue color* and resembles a star of the *ninth* magnitude. The *inclination* of the plane of the orbit of Phocœa to that of the ecliptic 0° 21′ 24″, her *solar distance* 228,100,700 miles, and her *periodic time* 1,359 days.

PROSERPINE. (26)

538. Mr. Luther of the observatory of Bilk, discovered the *twenty-sixth* planet of the asteroid group, on the 5th of May, 1853. It ranks in splendor between stars of the *tenth* and *eleventh* magnitude, and the *inclination* of its orbit is 3° 36′ 14″. *Proserpine* is *distant from the sun* 252,327,505 miles, and her *periodic time* is 1,581 days.

EUTERPE. (27)

539. This asteroid was found by Mr. J. R. Hind, on the 8th of November, 1853. It is inferior in brilliancy to stars of the *ninth* magnitude. *Euterpe's distance* from the sun, is 222,993,975 miles, and her *periodic time* 3.397 years, or 1,314 days. The *inclination* of her orbit is 1° 26′.

BELLONA. (28)

540. *Bellona* was discovered by Mr. Luther of Bilk, on the 1st of March 1854. The planet ranks in brightness with a star of the *tenth* magnitude, the *inclination* of

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Give an account of Themis, Phocœa, Proserpine, Euterpe, and Bellona.

its orbit is 9° 27′ 16″, and its *solar distance* 263,641,815 miles. Its *periodic time* is 1,689 days.

AMPHITRITE. (29)

541. This planet was discovered by Mr. Albert Marth of London, on the 2d of March, 1854. In brightness it resembles a star of the *tenth* magnitude. The *inclination* of its orbit is 6° 4′ 6″, and its *solar distance* is 242,712,270. The *periodic time* of *Amphitrite* is 1,492 days.

URANIA. (30)

542. This planetary body was discovered by Mr. J. R. Hind of London, on the 22d of July, 1854. It is another member of the group of asteroids, and in brightness is between the *ninth* and the *tenth magnitude.* The *inclination* of the plane of its orbit to that of the ecliptic is estimated at 0° 56′ 48″, and its *solar distance* at 224,598,905 miles. Its *periodic time* is 1,328 days.

EUPHROSYNE. (31)

543. On the 1st of September, 1854, Mr. Ferguson, of the observatory Washington City, D.C., detected the thirty-first asteroid which he named *Euphrosyne.* The *inclination* of her orbit, according to the calculations of Prof. Keith, is 22° 39′ 14″, and her *distance* from the sun 299,835,010 miles. Her *periodic time* is 2,048 days.

544. Mr. Ferguson enjoys the distinction of being the *first American* who has discovered a planet.

POMONA. (32)

545. This planet was discovered by Mr. Goldschmidt of Paris, on the 28th of October, 1854.

POLYMNIA. (33)

546. During the same day on which Pomona was dis-

Give an account of Amphitrite. What is known respecting the 30th asteroid? What in regard to Euphrosyne, and Pomona.

covered, Mr. Chacornac of Paris, found another asteroid which has received the name of *Polymnia*. The asteroids are so much alike that it is unnecessary to speak further of each separately. A list of all which have been discovered up to the present time (1863,) is given in the appendix (323, 324,) with their *solar distances*, *periodic times*, *dates* of discovery, and so forth.

547. THE SYSTEM PURSUED IN NAMING NEW PLANETS. Since the planets that have been long known were named after fictitious personages in classic mythology astronomers have in general, deemed it best to pursue, the same plan in giving appellations to those which have lately been discovered. A difference of opinion in this respect has however existed, and the planet has in some instances been named after the discoverer or some other distinguished person. There are several objections to the last method, and the original system will doubtless prevail.

548. OLBERS' THEORY. In regard to the bearing which the discovery of so many asteroids has upon the correctness of the theory of Olbers, Mr. J. R. Hind made the following remarks, when only the *fifteenth asteroid* was found. "The idea of the German astronomer has been so strongly countenanced by the discoveries of the last five years, that we can not fairly reject it until another theory has been advanced, which would account equally well for the peculiarities observed in this zone of planets, however unwilling we may be to admit the possibility of such tremendous catastrophes, and notwithstanding the great difference in the mean distances of Flora and Hygeia,[1] the innermost and outermost of the zone. Yet it is singular that this group appears to separate the planets of small mass, from the greater bodies of the system, the planets which rotate upon their axes in about the same time as the earth, from those which are whirled round in less than half that interval, though of ten times the diameter of our globe. And it may yet be

1. Euphrosyne, instead of Hygeia, is now the *outermost* planet of the asteroid group.

What in regard to Polymnia. According to what system are new planets named? Give the remarks of Mr. J. R. Hind in respect to the origin of the asteroids.

found that these small bodies so far from being portions of the wreck of a great planet, were created in their present state for some wise purpose, which the progress of astronomers in future ages may eventually unfold."

JUPITER. ♃

549. PERIODIC TIME—DISTANCE. Next in order from the sun is Jupiter, the most magnificent planet that illumines the sky. Its *periodic time* is 4,332 days, or somewhat less than *twelve* of our years. The *mean distance* of Jupiter is 495,817,000 miles, but owing to the eccentricity of his orbit this element is quite variable, for at his *perihelion* he approaches within 471,937,000 miles of the sun, while at his *aphelion* he recedes to the distance of 519,697,000 miles from this luminary. The difference between these two distances is 47,760,000 miles, an extent equal to one half the solar distance of the earth.

550. DIAMETER—APPARENT—REAL. This planet for the reasons already given (Art. 177,) appears larger to us in opposition than in conjunction; in the *former* position its *apparent* diameter measures 47″ and in the latter only 30″. The *real* mean diameter according to Prof. Struve is 88,780 miles.

551. ELLIPTICITY—BULK. The ratio between the *polar* and *equatorial* diameters derived from the most recent measurements is as 947 to 1000; but Prof. Struve considers the inequality to be greater, being as 85 to 92. Regarding the *first ratio* as correct, the polar diameter of Jupiter is less than the equatorial by more than 4,800 miles, a quantity exceeding the radius of the earth. The *bulk* of the planet is more than *twelve hundred* times greater than that of the earth.

552. PHYSICAL ASPECT OF JUPITER—BELTS. When this beautiful planet is seen through a telescope, no configurations are beheld on its surface, marking the positions of continents and seas, as is the case of Mars, but

What is the next planet in order from the sun? What is his *periodic time*? His *solar distance*? What is the difference between his *perihelion* and *aphelion* distances? What is the magnitude of his *apparent* diameter? What the extent of his *real diameter*? What is said respecting the *ellipticity* and *bulk* of this planet? How does Jupiter appear when viewed through a telescope?

dark bands termed *belts* are seen, stretching from side to side in the same direction. They are by no means uniform in their appearance, and although for months they sometimes remained unchanged, they are yet liable to sudden and extensive alterations in their *breadth* and *situation*, though not in respect to their *general direction.* In a few rare instances they have been seen broken up and distributed over the *entire disk of the planet.* Branches are frequently observed diverging from the main belts, and *dark spots* have likewise been noticed, of which astronomers have availed themselves to ascertain the period occupied by the planet in revolving on its axis.

The views generally entertained by astronomers in respect to the *cause* of the *belts* are the following. It is supposed that Jupiter is surrounded by a luminous *atmospheric* envelope, which conceals for the most part the planet itself, and that this bright canopy is parted by *narrow openings* parallel to the equator of Jupiter. That an observer on the earth *looking through these openings* sees the *dark surface* of the planet, and that the *glimpses* thus caught of the *solid body* constitute the *narrow dusky bands* or *belts.*

553. These *rents* in the atmosphere of Jupiter, are supposed to be caused by *currents*, like our *trade winds*, but vastly more powerful owing to the immense velocity with which the planet rotates, and the variations in the action of these winds upon the atmosphere of the planet would account for the changes that are noticed in the aspect of the belts. The appearance which Jupiter displays when seen through a telescope is shown in Fig. 74.

554. ROTATION. By observing a remarkable spot on Jupiter, Cassini, a distinguished Italian astronomer, ascertained in the year 1665, that this planet revolved upon its axis, completing a rotation in about 9h. 56m. Modern observations have established these conclusions, for the most able astronomers of the present day with the superior instruments they now possess, make the

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Describe the *belts* and their *changes*? What is the prevailing opinion of astronomers as to the *cause* of the belts? How are the changes in the appearance of the belts supposed to arise? At what time, and by whom, was the rotation of Jupiter ascertained and its period determined?

FIG. 74.

JUPITER AND HIS BELTS.

period of rotation very nearly the same. Mr. Airy the Astronomer Royal of England has fixed it at 9h. 55m. 21sec., and Mädler of Germany, at 9h. 55m. 30sec.

555. VELOCITY OF ROTATION. The velocity with which this planet revolves on its axis is immense. In less than *ten hours* a particle on the surface of the planet at its equator sweeps through the whole extent of its circumference, or 278,900 miles. Its velocity therefore exceeds 464.8 miles a minute, a speed *twenty times* greater than that of a cannon ball.

556. MASS—DENSITY. The *quantity of matter* in Jupiter, according to the latest researches of Prof. Bessel, is to the *mass* of the sun in the ratio of 1 to 1047.87; in other words the sun contains nearly *one thousand and forty-eight times* as much matter as Jupiter. The *density* of this planet is about *one-fourth* that of the earth, ($\frac{24}{100}$ths.)

557. SATELLITES OF JUPITER—THEIR DISCOVERY. A splendid train of four *moons* or *satellites* is seen by the aid of the telescope, circling around this planet. They were discovered by Galileo of Padua, on the 8th of January, 1610, and were the first fruits of his invention of

What is its *period?* What is said respecting the *velocity of rotation?* What of the *mass* and *density* of Jupiter? How many moons has Jupiter? By whom, when, and how were they discovered?

the telescope. From that time to the present they have ever engaged the attention of astronomers, and their *eclipses* have been eminently serviceable in certain scientific investigations of which we shall soon speak.

558. THEIR MAGNITUDES—DIAMETERS—DISTANCES—AND PERIODS OF REVOLUTION. No names have been given to these *moons*, but they are denominated the *first*, *second*, *third*, and *fourth* satellites, according to their distances from Jupiter, the *first* being the *nearest.* They shine as stars of between the *sixth* and *seventh* magnitude, but on account of their nearness to their brilliant primary, the telescope is needed to discern them. Their respective *diameters*, *distances*, and *periods of revolution* around Jupiter, are given in the table below.

	DIAMETER.	DIST. FROM JUPITER.	PERIODS OF REVOLUTION.
First Satellite,	2,440 miles,	278,500 miles,	1d. 18h. 27m. 34sec.
Second, "	2,190 "	443,000 "	3d. 13h. 14m. 36sec.
Third, "	3,580 "	707,000 "	7d. 3h. 42m. 33sec.
Fourth, "	3,060 "	1,243,500 "	16d. 16h. 31m. 50sec.

The *first two* satellites are *larger* than our *moon*, and the *last two greater* than the planet *Mercury;* the *diameter* of the third exceeding that of *Mercury* by 630 miles.

559. KEPLER'S LAWS—ROTATION. The satellites in their respective *distances* from the planet Jupiter, and in their *periodic times*, obey the *third* law of Kepler—the *squares* of their *periodic times* being as the *cubes* of their *distances* from their common primary. An extended series of observations upon the periodical changes in their light led Sir William Herschel to infer, that each of the satellites revolves on its axis in exactly the *same* time as it completes one *synodical revolution* about Jupiter, thus following exactly the same law as our moon does in respect to the earth.

560. The satellites as seen from the *equator* of Jupiter would present the following appearances. The *first* would seem somewhat larger than our moon. The *apparent diameters* of the *second* and *third* would be about

Why are they regarded with interest by astronomers? State their *magnitudes*, *diameters*, *distances*, and *periodic times?* How do they compare in their actual dimensions with our moon and Mercury? Does Kepler's third law apply to the satellites? State what is said in regard to their rotation?

two-thirds of that of the sun as viewed from the earth, while the *apparent diameter* of the *fourth* would be equal to *one-quarter* of that of the *first.* The planes of the orbits in which the satellites revolve, deviate but little from the plane of the planet's orbit, and as the apparent diameter of the sun as seen from Jupiter, is only about *one-sixth* of the apparent diameter of the *first* satellite, *solar eclipses* must be of common occurrence to the residents at Jupiter's equator, if any such residents there are.

561. TRANSITS AND ECLIPSES OF THE SATELLITES. The satellites revolve about Jupiter from *west* to *east*, and in planes nearly coincident with each other. They are therefore seen ranging together in almost a *straight line*, and seem to move backwards and forwards in the heavens, now passing in *front* of the planet, and now *behind* it.

562. When they pass *before* the planet their *transits* occur, and they cast *shadows* upon their primary which appear as *dark spots* crossing its bright disk. With powerful telescopes the satellites are occasionally seen as *luminous spots*, if projected on a dark belt; and at other times as *dark spots* of smaller size than their shadows—a circumstance which is accounted for by supposing that the satellites themselves have sometimes *obscure* spots of great extent, either *on their own bodies* or in their atmospheres.

563. In passing *behind* the body of the planet or into its shadow at a distance from it, the satellites *disappear* and their *eclipses* occur. The *three* satellites which are nearest to Jupiter are *totally* eclipsed, every revolution around their *primary*, but the *fourth*, from the greater inclination of its orbit, sometimes escapes being eclipsed; yet so seldom, that its eclipses may be regarded as happening, for the most part, at every revolution like those of the others.

What would be the respective apparent magnitudes of the satellites if seen from Jupiter's equatorial regions? Why are *solar eclipses* of frequent occurrence at this planet? In what direction do the satellites revolve about Jupiter? Why are they seen in a straight line with each other? How do they appear to move in the heavens? When do their *transits* occur? Describe them? Why do the satellites sometime appear as dark spots on the disk of Jupiter? Under what circumstances do their *eclipses* happen? State what is said of their frequency?

564. By the aid of these latter phenomena, astronomers have been enabled to construct tables of the motions of the satellites, and likewise to determine approximately the *longitudes* of places upon the earth. Moreover, by their means the *velocity of light* has been ascertained. This discovery was made under the following circumstances.

565. VELOCITY OF LIGHT. In the year 1675, Olaus Roemer, a Danish astronomer, noticed that if the calculation of an eclipse of a satellite was made upon the supposition that it would happen when Jupiter was in *opposition*, and the eclipse took place when the planet was in *conjunction*, that the *actual time* of the eclipse *was later* than the *computed time* by 16m. 26,6sec. On the contrary, if the calculation was made in view of Jupiter, being in *conjunction*, and the eclipse took place when he was in *opposition*, that then the *actual time* of the eclipse was *earlier* than the *predicted* by 16m. 26,6sec.

566. Now the *difference* of the distances of Jupiter from the earth when in *conjunction* and *opposition* is the *diameter of the earth's* orbit, or about 190,000,000 miles. This is evident from Fig. 75, where S represents the sun, E the earth, EO its orbit, JO^1J^1 the orbit of Jupiter, J the position of Jupiter in *conjunction*, and J^1 at *opposition.* Now the distance of Jupiter from the earth at *conjunction* is equal to Jupiter's solar distance (JS,) *added* to the earth's solar distance (ES,) but at *opposition* it is equal to Jupiter's solar distance (J^1S,) *diminished* by the earth's solar distance (ES.) The difference in the distances of Jupiter from the earth, at opposition and conjunction is therefore equal to *twice* the earth's distance from the sun (EO,) or nearly 190,000,000 miles.

567. Roemer suspected that the difference between the *actual* and *predicted* times of an eclipse, was owing to the circumstance that the light from the satellite had to travel *farther* in coming to the earth, when the planet was in conjunction than when in opposition, and it was therefore inferred that light passed through the space of

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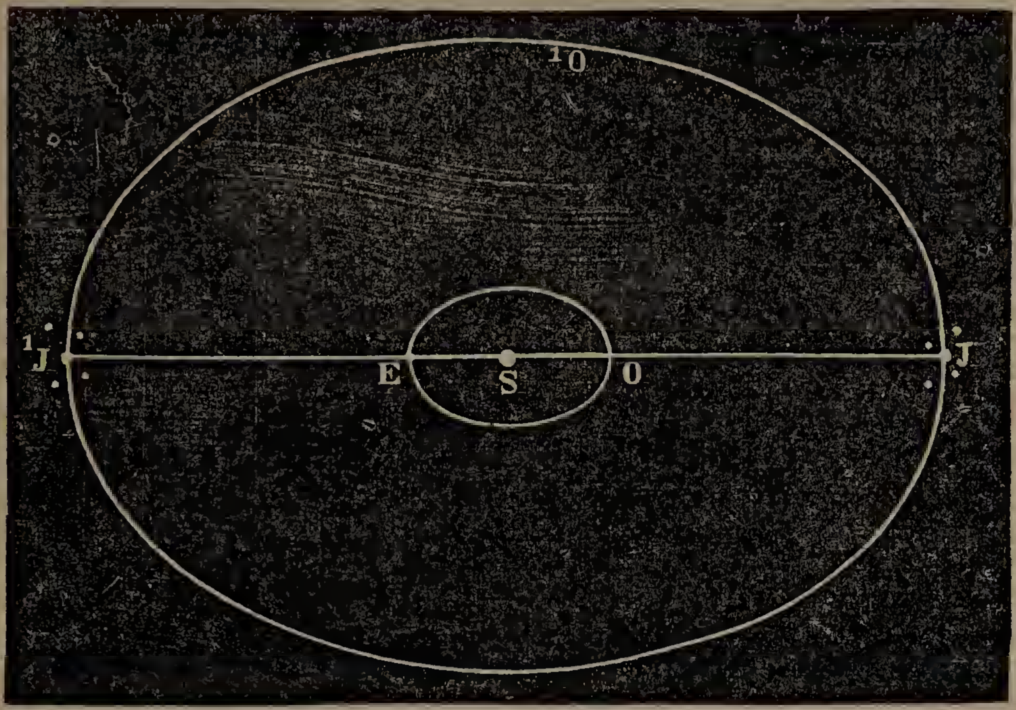
In what particulars have these phenomena subserved the interests of science? State when, and by whom the *velocity of light* was ascertained? Give a full account of this discovery, explaining from Figure.

FIG. 75.



VELOCITY OF LIGHT.

190,000,000 miles in 16m. 26,6sec, or 192,000 miles *per second.*[1] This conclusion has since been fully established, for *two other* independent modes of computing the velocity of light have since been discovered, both of which give substantially the same result as is afforded by the first.

568. The most ancient observation of Jupiter on record was made at Alexandria, on the 3rd of September, 240 years before Christ, when the planet was seen to *eclipse a certain star in the constellation of the Crab*

SATURN. ♄

569. The next planet is *Saturn ;* a vast globe inferior in magnitude only to Jupiter, but surpassing it in the wondrous structure of its system, for Saturn is attended by a train of no less than *eight satellites* and is girdled by several *rings* of stupendous size.

1. The velocity per second is obtained by *dividing* 190,000,000 miles by 16m. 26,6sec. *reduced to seconds.* In 16m. 26,6sec., there are 986,6sec., dividing 190,000,000 miles by this number we obtain as a quotient 192,600 miles, which is the velocity of light per second.

What is the velocity of light per second as obtained by Roemer ? Is this computation correct ? Why ? What is the most ancient observation of Jupiter on record ? What planet is next discussed ? What is said of its grandeur ?

570. Distance—Periodical Revolution and Inclination of Orbit. The *mean solar distance* of Saturn, is 909,028,000 miles, but on account of the *eccentricity* of his orbit, he is distant from the sun at his *aphelion* 960,070,000 miles, and at his *perihelion* 857,986,000 miles. The *solar distance* of the planet thus varies more than 102,000,000 miles. The *time* employed by Saturn in making *one siderial revolution* is 29½ years. The *inclination* of the plane of its orbit to that of the ecliptic is 2° 29′ 36″.

571. Form and Diameter. From an extended course of observations Sir William Herschel was of opinion, that the disk of Saturn differed in form from that of the other planets of our system; for instead of being *oval*, it seemed an *oblong* or *parallelogram* with the corners *rounded off.* This view was generally adopted by astronomers until a series of actual measurements, made by Prof. Bessel of Konigsberg, and Mr. Main of the Royal Observatory of England, revealed the error, and proved that the disk of Saturn does not deviate sensibly from an *ellipse.* The form of the planet is therefore *spheroidal.* According to Prof. Bessel, the ratio of the *equatorial diameter* of Saturn to the *polar* is as 1000 to 903. The actual *length* of the *former*, deduced from the latest and most exact observations, is 77,230 miles, that of the *latter* computed from the preceding ratio will consequently be 69,738.7. The difference being 7,491 miles an *extent* nearly equal to the *diameter* of the earth.

572. Bulk—Density—Intensity of Light. Saturn is nearly *one thousand times* larger than the earth. His *density* is but *one-seventh* that of our planet ($\frac{14}{100}$ths), therefore, *seven cubic feet* of Saturn, would on an average contain the same amount of matter as *one cubic foot* of our globe. The *intensity* of the *solar light* at Saturn is 90 times *less* than it is at the earth.

573. Physical Aspect—Atmosphere. Saturn appears of a *pale yellowish hue*, and when viewed through a good telescope *belts* are frequently seen upon its surface,

Tell of its *solar distance, periodic time*, and of the *inclination of the plane of its orbit?* State what is said in regard to its *form?* What is the true form of the planet? What is the ratio of the *equatorial* to the *polar* diameter of Saturn according to Prof. Bessel? What their respective lengths in miles? How great is their difference? State what is said respecting the *bulk* and *density* of Saturn? What in regard to his *degree of illumination?*

but far more faint and obscure than those which are revealed upon the disk of Jupiter. *Spots* are rarely noticed on this planet.

574. The *changes* in the *number* and *appearances* of the belts, led Sir William Herschel to think, that Saturn is enveloped in an atmosphere of *great density.* In this opinion he was strengthened by the circumstance, that when the *nearest* satellites of Saturn in the course of their revolutions passed behind the planet, they seemed, as they *approached* and *receded* from its edge, to remain upon it *too long;* the satellite which is closest to the planet lingering *twenty minutes* behind its computed time, and the next *fifteen.* This detention was only to be accounted for by the *refraction of the light* of the satellite through an *atmosphere* surrounding Saturn.

575. About the polar regions of this planet, the same astronomer repeatedly observed recurring changes in its light, and the appearance of extensive *cloudy spaces,* which likewise increased the evidence of the existence of a dense atmosphere.

576. ROTATION AND INCLINATION OF ITS AXIS. In 1793, Sir William Herschel instituted a most diligent and thorough observation of the *belts*, for the purpose of determining the time of the *rotation* of Saturn. He watched and noted them with great care through *one hundred* rotations, examining them under varied *circumstances* and *aspects*, and at length came to the conclusion that Saturn completes a revolution on his axis in 10h. 16m. 4sec.; a result which Herschel was certain could not deviate from the truth by so much as two minutes. The *axis* upon which Saturn revolves is inclined to the plane of its orbit 63° 10′, a position which tends to give to the planet nearly the same diversity of seasons as that which our earth enjoys.

577. RING OF SATURN—ITS DISCOVERY. When Galileo in the year 1610, directed his telescope to Saturn, the figure of the planet appeared so singular, that he thought

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Describe the physical aspects of this planet? What circumstance led Sir William Herschel to believe that Saturn possessed a dense atmosphere? State by *whom*, and in what manner the rotation of the planet was ascertained? What is the *period of rotation* as determined by Herschel? Is it exactly correct? What is the *inclination of the axis* of rotation to the plane of the planet's orbit? What is said of the *seasons* of this planet?

it consisted of a *large globe* with a *smaller one on each side.* About 50 years afterwards Huyghens, a distinguished Dutch philosopher, observed Saturn with telescopes of greater magnifying power than those which had been employed by Galileo, and soon made the discovery that the planet was surrounded by a *vast luminous ring*, *unconnected* with the body of the planet.

578. When the telescope had been still farther improved, and instruments of higher magnifying powers and finer construction were at command, two English gentlemen of the name of Ball, in October, of the year 1665, *first* noticed that the ring was *double;* a phenomenon which was observed by Cassini at Paris, 1675, and to whom the honor of this *second* discovery is usually attributed. Of the *later* discoveries mention will be made in a succeeding article. At present while discussing certain particulars respecting this wonderful appendage, we shall speak of it as one ring.

579. Form—Constitution. The ring may be described as *circular*, *broad*, and *flat*, like a coin with a *round central* opening. Like the planet it shines by the reflected rays of the sun and has usually been supposed by astronomers to consist of *solid matter*, since it *casts a shade* upon the surface of the planet when it is situated *between* the latter and the sun. Profs. Pierce and Bond, of Harvard University, have however arrived at the conclusion that the ring of Saturn is not *solid* but *fluid.* Prof. Pierce remarks, "that the ring of Saturn consists of a number of *streams* of some *fluid* about *one-fourth heavier* than *water*, flowing around the planet."

580. Rotation—Position—Inclination to the Ecliptic. From the observations made upon certain spots on its surface, Sir William Herschel inferred that the ring rotated in its own plane in the space of 10h. 32m. 15sec.; a period precisely the same as that which La Place proved it ought to have, according to the theory of universal gravitation. The *plane of the ring* is exactly coincident with the *plane of the planet's equator* and is *inclined* to the ecliptic at an angle of 28° 10′ 27″.

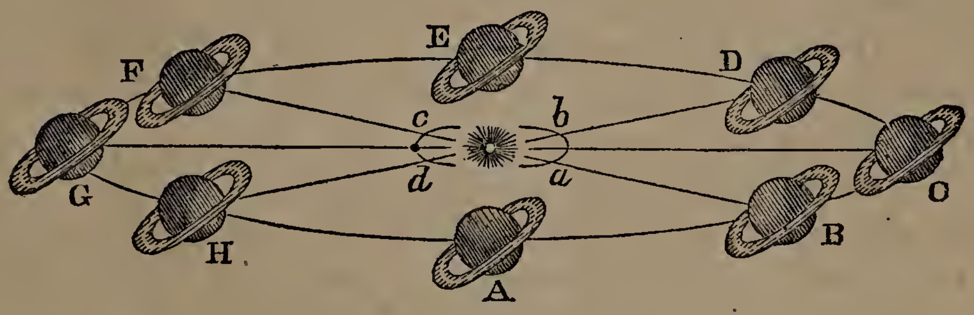
Give an account of the discovery of Saturn's ring? What is said respecting its *form* and *constitution?* What of its *rotation, position,* and *inclination?*

581. PHASES OF THE RING. When viewed through a telescope at considerable intervals of time the ring of Saturn presents different aspects. For at one time it appears *broad* and *flat* and of an elliptical shape, with an open space between it and the planet, while at another it is *narrowed down* and looks like two handles projecting from each side of the planet; and then again it *vanishes* entirely from our sight.

582. The *causes* of these changes are found in the following facts; FIRST, that the ring, like the *earth's axis*, always remains *parallel to itself*, and SECONDLY, that we view it in *different positions* at *different times*.

583. This subject is illustrated in Fig. 76, where the

FIG. 76.



SATURN AND HIS RING.

curve *abcd*, represents the *orbit* of the earth, the *central figure* the *sun* and A, B, C, D, E, F, G, H, *eight* positions of Saturn in his orbit. Now if we were stationed upon the sun, Saturn being at C, the solar light falling upon the *flat* surface of the ring would be reflected back to us, and we should see the ring in its *greatest breadth;* the *opening* between the planet and the ring, would likewise be readily discerned. But as the planet in its orbitual motion advanced to D, the *visible* portion of the ring would *contract*, since we should now view its surface more *obliquely* than we did at first.

584. When Saturn had arrived at E, where the *plane of the ring passes through the sun*, the solar rays would fall only on the *edges* of the ring, which is so thin that the reflected light would be too faint to render it visible.

Describe the phases of the ring? Illustrate by the aid of Figure 76

In this position the ring consequently would *vanish* from our sight. As the planet advanced successively to F and G, the *visible surface* of the ring would gradually *increase*, attaining at G the same apparent breadth and exhibiting the same aspect as it possessed at C. Saturn continuing his progress to A, would once more *contract* in size, becoming *invisible* at A where its plane passes again through the sun. From A to C, the apparent surface of the ring would gradually *increase* regaining at C its original *breadth* and *appearance*.

585. In the above illustration we have discussed the phases presented by the ring as *viewed from the sun*, but our point of sight is the *earth* situated somewhere in the orbit *abcd*. This circumstance modifies somewhat the appearance of the ring as explained above, but not to any very great extent, for the earth is so much *nearer* the sun than Saturn is, that the ring exhibits to us almost exactly the same aspects as if we *actually* beheld it from the sun.

586. VANISHING OF THE RING—THREE CAUSES. Our position upon the earth multiplies however the causes of the disappearance of the ring. Since it appears to us very nearly as it would to a spectator upon the solar orb, we in the *first place* lose sight of it when its *plane passes through the sun;* unless telescopes of the greatest power and finest construction are employed, when à *faint line of light* is just perceived marking the position of the ring. In the *second place* the ring *vanishes* when its *plane passes through the centre of the earth*, for then its *edge* only is directed to us which does not reflect light enough to become visible. *Lastly*, when the *plane of the ring passes between the earth and the sun*, it disappears from our sight, because the side which is illumined by the sun's rays is then turned from us, and the *dark side* presented towards us. Thus in the figure, such would be the case if the earth was somewhere between *c* and *d*, while Saturn was a little distance from E moving towards F, yet not

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Does Saturn and his ring appear nearly the same from the earth as it would from the sun? State the *three causes* of the disappearance of the ring, and explain why the ring will vanish when it is in any one of these three positions? Can the ring be discerned in any way when its plane passes through the sun?

so far from E but that the plane of the ring would *pass between the earth and the sun.*[1]

587. DIVISIONS OF THE RING. We have already alluded to the discovery made by the Messrs. Ball, and also by Cassini, that the ring of Saturn is *double.* For nearly a century, astronomers have been led to think from the appearance of *dark lines* upon the ring that other subdivisions exist, and these surmises have proved correct.

588. In 1837, Prof. Encke of Berlin, saw through the famous telescope of Fraunhofer, the *outer ring* of Saturn divided by a *black line* and so clearly defined that he was enabled to take the measurements of its breadth. This separating line was observed some years afterwards by Messrs. Lassel, Dawes, and Hind, and also by Prof. Challis of Cambridge University, England, and with such marked distinctness as to leave no doubt of the *actual division* of the *outer ring.*

589. But this discovery was soon followed by another still more surprising, which was no less than the detection of a *dusky obscure ring, nearer* to the planet than what is usually termed the *bright inner ring.* On the 11th of November, 1850, Mr. G. P. Bond, of Harvard University, saw such evidences of subdivision in the *inner ring* as led him to infer that a *third ring* existed *nearer* the planet and less bright than the other two. On the 29th of the same month, the Rev. W. R. Dawes, of Wateringbury, England, made the same discovery, and noticed likewise the additional fact that the *dusky ring* is itself *double;* being divided by an extremely fine line.

1. Mr. J. R. Hind thus speaks of the late *phases* of Saturn's ring. "In 1848, after the *north surface* had been *visible* for nearly 15 years, the ring became invisible on April 22d, when the earth was in the plane of the ring; It *reappeared* on the 3d of September, when the sun was so situated in respect to the ring as to illumine the *southern* surface, which was turned towards us. On the 12th of the same month, the earth passed to the *northern side* of the ring, while the sun still shone on the *southern side*, and the ring consequently *disappeared a second time.* It continued *invisible* to us until the 18th of January, 1849, when the earth passed to the *southern* side of the ring which had been turned towards the sun since the 3d of September, 1848. We shall continue to see the *southern* surface of the ring until the close of the year 1861."

Relate in full the discoveries that have been made in respect to the divisions of the ring?

590. What therefore was at first regarded as a *single* ring is now found to consist of *five*; viz., *two obscure rings* nearest the planet, and *three bright ones* beyond them. The *two exterior luminous* rings constitute what has hitherto been termed the *outer ring* of Saturn, and the *third* the *inner ring*. Fig. 77, represents Saturn and

FIG. 77.

SATURN AS VIEWED BY THE REV. W. R. DAWES, ON NOVEMBER 29TH, 1850.

his rings as they appeared to Mr. Dawes of Wateringbury, when viewed through a telescope of the finest construction. The *division* of the *dark inner ring* is however not delineated.

591. DIMENSIONS OF THE RINGS. The dimensions of the *outer* and *inner*[1] *rings* of Saturn have been determined by the most accurate and careful measurements to be as follows:

From the surface of the planet to the *inner* edge of the *first* bright ring, ...	18,628	miles.
Breadth of the inner ring, ...	16,755	"
Breadth of the interval between the bright inner and outer ring, ...	1,752	"
Breadth of the outer ring, ...	10,316	"
Outer diameter of the outer ring, ...	172,130	"

1. *Outer* and *inner ring*. By the *outer ring* is here meant as stated in the preceding article, the *two exterior bright* rings. The *inner* ring is the *third bright* ring, next to the *dark* one.

How many rings have been found? Give the dimensions of the *outer* and *inner* rings of Saturn?

592. The *thickness* of the rings has been estimated by Sir John Herschel, at not more than 100 miles, while Mr. G. P. Bond, of Cambridge, places the thickness as low as 40 miles.

593. SATELLITES OF SATURN. Saturn is attended by *eight* moons, *seven* of which revolve about the planet in orbits, whose planes are nearly *coincident* with that of the ring. They have received the names of *Mimas*, *Enceladus*, *Tethys*, *Dione*, *Rhea*, *Titan*, *Hyperion*, and *Japetus*.

594. On account of their great distance from the earth these bodies, although possessed of considerable size, are only visible by the aid of powerful telescopes. We shall describe them briefly, commencing with the one nearest to Saturn, and taking them in the order of their distances from the planet.

595. MIMAS. This satellite was discovered by Sir William Herschel, on the 17th of September, 1789, with his immense reflecting telescope of 40 feet focal length. The largest instruments and the most favorable circumstances are needed to see this moon merely as a *small bright point*. Such is the extreme difficulty of detecting it, that few astronomers have even beheld it. The *mean distance* of Mimas from the centre of Saturn is 118,000 miles, and it *revolves* about the planet in 22h. 36m. 18sec. It is *distant* from the ring about 32,000 miles.

596. ENCELADUS. On the 19th of August, 1787, Sir William Herschel first noticed this satellite, before his great telescope was completed. The discovery was confirmed by the aid of this noble instrument in August, 1789. Enceladus has been observed by Sir John Herschel several times, shining like a star of the *fifteenth magnitude*. It *revolves* about Saturn in 1d. 8h. 53m. 7sec., and its *distance* from the centre of the planet is 152,000 miles. The plane of its orbit according to Sir William Herschel's observations is coincident with that of the ring.

597. TETHYS. This satellite was found by Cassini,

What is the thickness of the rings according to Sir John Herschel? What according to Mr. G. P. Bond? How many moons has Saturn? What is the position of the planes of the orbits of *seven*? Give the names of the satellites? What is said as to their visibility? State in full what is said of *Mimas*, and *Enceladus*?

in March, 1684. It resembles a star of the *thirteenth magnitude*, and performs its revolution around Saturn in an orbit the plane of which is nearly if not exactly coincident with that of the ring. It *completes* a *revolution* around its primary in the space of 1d. 21h. 18m. 26sec., at the *distance* of 188,000 miles from the centre of the latter.

598. DIONE. Dione was likewise discovered by Cassini, in March, 1684. In size it varies between the *eleventh* and *twelfth magnitude*, and its *distance* from the centre of Saturn, is equal to that of our moon from the earth, being 240,000 miles. Dione revolves in an orbit supposed to be coincident with that of the plane of the ring and *performs its revolution* in 2d. 17h. 44m. 51sec.

599. RHEA. Cassini detected this moon of Saturn on the 23d of December, 1672. It shines usually like a star of the *tenth* or *eleventh magnitude*, but at times, appears as one of the *ninth*, and then again of the *twelfth magnitude;* its brightness depending much on its position in respect to Saturn, and also on the state of our atmosphere. The plane of the orbit of this satellite, nearly coincides with that of the ring. Rhea *revolves about* its primary in 4d. 12h. 25m. 11sec., and is *distant* 336,000 miles from its centre.

600. TITAN. This is the *largest* of all the satellites of Saturn, and shines as a star of the *eighth magnitude.* It was discovered by Huyghens, on the 25th of March, 1655, and has recently been studied with great care by Prof. Bessel. Titan *revolves* about Saturn at the *distance* of 778,000 miles from its centre, *performing a revolution* in the space of 15d. 22h. 41m. 25sec.

601. HYPERION. This satellite was discovered as late as September, 1848, and almost at the same time by two observers. Mr. G. P. Bond, of Harvard University, detected it on the 16th of September, and Mr. Lassel, of Liverpool, on the 18th of the same month.

Hyperion appeared to Prof. Bond, as a star of the *seventeenth magnitude.* Its *distance* from Saturn and

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Give an account of *Tethys, Dione, Rhea, Titan, Hyperion.*

period of revolution have not yet been very accurately de termined, the *former* however, is not far from 940,000 miles, and the *latter* 21d. 4h. 20m.

602. JAPETUS. This is the *most remote* of all the satellites of Saturn. Its *distance* from the centre of its primary is no less than 2,268,000 miles, and its *period of revolution* 79d. 7h. 54m. 41sec. The plane of the orbit of this satellite is inclined to that of the ring about 10°. Japetus, was discovered by Cassini, towards the close of the month of October, in the year 1671. *Periodical changes* in the light of this satellite have been noticed, which lead to the inference that it *revolves on its axis* in the *same time* that it *completes a revolution* around Saturn, just as our moon does in respect to the earth—a *law of revolution* which probably exists in the case of all the satellites belonging to the planets of our system.

603. DIAMETERS OF THE SATELLITES. Of these measurements we have little knowledge. Prof. Struve has reckoned the diameter of Titan, the *largest*, to be 3,300 *miles*, which is regarded as not far from the truth. Schroeter estimated the *diameter* of Titan at 2,850 miles, that of Japetus at 1,800 miles, of Rhea 1,200, and the diameter of Dione and Tethys at 500 each. Sir William Herschel supposed Mimas to be 1000 miles in *diameter.*

604. Sir John Herschel has detected a singular relation between the *periods of revolution* of the *four interior* satellites; viz., that the *periodic time* of Mimas is *one-half* that of Tethys, and the *period* of Enceladus, *one-half* that of Dione. The rotation is almost mathematically exact. The laws of Kepler, hold true in regard to Saturn's satellites, as well as in the case of Jupiter's.

605. ANCIENT OBSERVATIONS OF SATURN. The most ancient observation of Saturn on record, was made by the Chaldeans, on the 1st of March, 228 years before Christ. On the 21st of February, 503 A.D., the planet was seen at Athens, apparently emerging from behind the *moon.*

Give an account of *Japetus?* What is said respecting the diameters of the satellites? What singular relation has been noticed by Sir John Herschel? What is here said in respect to the application of Kepler's laws? What ancient observations have been recorded of Saturn?

URANUS, OR HERSCHEL. ♅

606. Until the year 1781, all the known planets, excluding our earth, were *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*. Each of these, more or less conspicuous to the unaided eye, had been recognized as *planets* for ages, but about this time, Sir William Herschel, having constructed telescopes of great power, commenced a systematic examination of the heavens, which led to the most surprising discoveries.

607. On the 13th of March, 1781, between ten and eleven o'clock, this eminent astronomer detected an object which he at first suspected to be a comet, but subsequent observations established its planetary nature. The *new planet* was called by Herschel *Georgium Sidus*, as a compliment to his patron, George III., and by others, *Herschel* in honor of the discoverer; but the name proposed by Bode of *Uranus*, is now universally adopted.

608. Aspect—Diameter—Mass—Density. Uranus appears of a *pale color*, uniformly bright, and undeversified with *spots*, *belts*, or *configurations of surface* such as are seen on Jupiter and Mars. Its *diameter* is about 35,000 miles, and like other planets it is probably *elliptical in form*, having its *equatorial* diameter *longer* than its *polar*. This *difference* has not yet been satisfactorily established. Prof. Mädler thinks he has detected it, and makes the *ratio* of the equatorial diameter to the polar to be as 10 to 9. But other astronomers, with telescopes of greater power, have been *unable* to discern any *difference* at all in the *lengths* of the various diameters of the *planet*. According to the recent calculations of Mr. Adams, the sun contains 21,000 times as much matter as Uranus. The *density* of Uranus is exactly the same as that of Jupiter, or about $\frac{1}{4}$th of that of the earth.

609. Rotation. The *absence* of *spots* and *outlines* upon the unvarying bright surface of Uranus, deprives astronomers of the means of determining the period of its rotation. In fact whether it *revolves at all* upon its

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When was Uranus discovered, and by *whom?* What are the various names of this planet? State what is said in regard to its *aspect*, *diameter*, *mass*, and *density?*

axis is a point not yet fully determined, but as it belongs to a *system* of planets, *all the rest* of which revolve on their axes, it is reasonable to infer from analogy that Uranus also does.

610. DISTANCE—INCLINATION OF ORBIT—PERIODIC TIME. The *average distance* of Uranus from the sun is 1,828,071,000 miles, his *least* distance 1,742,738,000 miles, and his *greatest* 1,913,404,000 miles. Thus on account of the eccentricity of its orbit, the difference between the *perihelion* and *aphelion* distances of the planet is no less than 170,666,000 miles—an extent nearly twice as great as the distance of the earth from the sun. The *plane of the orbit* of Uranus almost *coincides* with that of the *ecliptic*, for its *inclination* is less than 47′. Uranus *revolves* about the sun in 30686.7 days, a little more than 84 of our years.

611. SATELLITES OF URANUS. Uranus was found by Sir William Herschel to be attended by *six satellites*, but notwithstanding the zealous efforts of astronomers, little certain knowledge has yet been gained in respect to their elements.

612. The *second* and *fourth* satellites, in the order of distance from the planet, are those that are best known; the periodical revolution of the former, being according to the computations of Mr. Adams,[1] 8d. 16h. 56m. 25sec., and that of the latter, 13d. 11h. 6m. 55sec. Uranus every year is becoming more and more favorably situated for observation, and there is every reason for believing that our knowledge of this planet will ere long be more complete than it is at present.

613. The *satellites* of Uranus differ in two *particulars* from all the other planetary bodies that compose the *solar system*. For all the planets and their satellites, excepting those of Uranus, revolve in their orbits from *west* to *east*, and the *planes of their orbits* do not deviate far from the *plane of the ecliptic*; but the attendants of Uranus move

1. The computations of Mr. Adams, are the most recent and are considered the most correct.

What of its *rotation, distance, inclination of orbit* and *periodic time*? How many satellites has Uranus? What do we know respecting them? Have they any peculiarities? What are they?

around the planet from *east* to *west*, and the *planes of their orbits* are nearly *perpendicular* to the *plane of the ecliptic*, being inclined to it at an angle of 78° 58′.

614. INTENSITY OF LIGHT. Since Uranus is about 19 times as far from the sun as the earth is, the *intensity* of the solar light is here *diminished* in the ratio of 1×1 to 19×19 (361.) In other words the *intensity* is 361 times *less* at Uranus than it is at the earth.

NEPTUNE.

615. HISTORY OF ITS DISCOVERY. When an astronomer knows perfectly all the *elements* of a planet, he can tell at what time it will be in a particular place in the heavens, with greater precision than the station-master of a rail-road can tell when a certain train will arrive at a given station. If the planet does not arrive at its *appointed place* at the *computed time*, it must be owing to some *influence unknown* to the *astronomer*, provided he has made no error in his calculations. Now Uranus, ever since its discovery, has not *kept its appointments*, for astronomers have been constantly finding it in a different place from that in which it ought to have been according to their calculations. It was always off the track, and they at length suspected that these deviations were caused by the attraction of a *planet hitherto undiscovered.*

616. Mr. Adams of St. John's College, Cambridge, in 1843, and Mr. Le Verrier, of Paris, in 1845, unknown to each other, undertook the task of solving this intricate problem, calculating *how large* a planet would account for these deviations, *what distance* it must be from the sun, *what orbit* it must have, and various other particulars. In September, 1846, the French astronomer had so fully completed his computations, that on the 23d of the month, he wrote to Dr. Galle, of Berlin, telling him *where* to look in the heavens for the *unknown planet* and of *what size* it would appear. Dr. Galle, the same evening he received the letter, pointed his instrument to that region in the heavens where he had been directed

How *intense* is the *solar light* of Uranus? What is the next planet in order? Give the history of the discovery of Neptune?

to gaze, and there he immediately saw a star of the magnitude mentioned by Le Verrier, and which proved to be the planet sought.

617. NAME—DIAMETER—MASS—DENSITY. The planet of Le Verrier has generally received from astronomers the *name* of *Neptune*.[1] Its *diameter* deduced from measurements made with the best instruments of Europe is 31,000 miles. Its *mass* is not yet accurately known, but from the computations of several very able astronomers, it is ascertained that the sun contains about 18,000 *times more matter* than Neptune. The *density* of this planet is estimated to be just equal to that of Saturn, or about $\frac{1}{6}$th of the *density* of the earth.

618. ORBIT—INCLINATION OF ORBIT—DISTANCE—PERIODIC TIME. The most accurate determination of Neptune's orbit was made by Mr. Sears C. Walker, of Philadelphia. Like that of the other planets it is elliptical, yet but moderately so, and its plane is *inclined* to that of the ecliptic 1° 47′. The *mean solar distance* is 2,862,457,000 miles, and the *difference* between its *greatest* and *least distance* from the sun is 49,940,000 miles, an extent considerably less than *one-third* of the like variation of Uranus. Neptune *revolves* about the sun in 60127.71 days, or about 164½ *years*.

619. INTENSITY OF LIGHT. As this planet is about 30 times *farther* from the sun than the earth is, the *intensity* of the solar light at Neptune, is 900 (30 × 30) times *less* than it is at the earth.

620. HAS NEPTUNE A RING. Mr. Lassel, of Liverpool, and Prof. Challis, of Cambridge, England, have at various times supposed that they saw traces of a ring surrounding the planet. Prof. Bond, of Cambridge, has frequently noticed a *luminous appendage*, but not so defined

1. Several names were proposed for this planet, Dr. Galle wished to to call it Janus. Other astronomers, Le Verrier, after the eminent mathematician whose profound researches led to its discovery, but the name of Neptune has been adopted by most astronomers, and approved of by M. Le Verrier himself.

What is said respecting the *name* of this planet in the text, and note? What of its *diameter*, *mass*, and *density*? What is said of the *orbit* of Neptune and its *inclination*? What of his *solar distance* and *periodic time*? What is the *intensity of solar light* at Neptune compared with that at the earth?

as to enable him to announce the *existence* of a ring. Other able astronomers, with some of the best instruments at command, have not even detected any peculiarity in the aspect of the planet, which would lead them to suspect that it was encircled by a ring.

621. THE SATELLITE OF NEPTUNE. In about a month after the discovery of Neptune by Dr. Galle, Mr. Lassel, of Liverpool, detected a satellite, shining like a star of the *fourteenth magnitude.* From all the observations made by this astronomer, and others, up to the end of the year 1848, it appears, that the satellite revolves about Neptune in an orbit *nearly circular*, that it *completes a revolution* about its primary in 5d. 21h., and at the mean distance from the latter of 232,000 miles. This moon of Neptune is at about the same distance from the planet as our moon from the earth; and Mr. Lassel discovered the interesting fact, that there are such periodical changes in its brightness, as to indicate that this satellite like others belonging to our system, rotates on its axis in the *same time* that it revolves around Neptune.

622. Mr. Bond, of Cambridge, believes that he has obtained tolerably good evidence of the existence of a *second* satellite, more dim and distant than the first, but not enough to enable him as yet to pronounce decidedly upon it. The fact that the more remote planets are attended by trains of satellites, and the singular *unresolved appearance* observed near Neptune, by the English and American astronomers, render it not improbable that an assemblage of moons may be at length found, circling around this far distant member of our system.

REAL AND APPARENT MOTIONS OF THE PLANETS.

623. A spectator *upon the sun* would see *all the planets revolving* with beautiful precision around this luminary from *west to east*, and constantly pursuing the same direction. Such are the *real motions* of the planets in their orbits. A person *upon the earth*, sees only the

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Has Neptune a *ring?* Give an account of the *satellite* of Neptune? Is the existence of a *second moon* suspected? May Neptune possibly have many satellites? State what is meant by the *real motions* of a planet?

apparent motions of these bodies, which differ so widely from their *real motions*, that a superficial observer might imagine that they actually *wandered* in the heavens, and were guided by no law. For at one time we behold a planet pursuing its *direct course* from *west to east*, after a while it becomes *stationary*, and then in a short time it resumes its motion, moving in a *retrograde course* from *east to west.*

624. The *apparent* motions of the inferior *planets* are quite complicated, and vary in some respects from those of the *superior planets* on account of their different positions in regard to the earth—the *former* having an *inferior conjunction* and *no opposition*, and the *latter* an *opposition* and *no inferior conjunction.*

625. Causes of the Apparent Motions. The *apparent motions* of the planets are owing to *two causes.* *First*, that we behold them from a *stand-point* above 95,000,000 miles from their centre of motion, and consequently see them in a different quarter of the heavens from that in which they would appear, if seen from the sun. *Secondly, the earth is not stationary*, and when we observe the planets, we assign to them the motion that belongs to the globe on which we stand, since we are unconscious that it moves at all.

626. Apparent motions explained. Selecting one of the *superior* planets, we will now endeavor to explain why its *apparent* motions differ so much from its *real.* Let Jupiter be that planet, and suppose him to be on the other side of the sun, in *superior conjunction.* He will then be seen to move in the *same direction* as the earth, that is from *west* to *east*, and as we are unconscious of our own motion, the *apparent* motion of Jupiter will *equal* his own *real* motion *added* to that of the earth. When Jupiter is near *opposition*, the *planet* and the *earth* are moving as it were on *parallel tracks*, with the starry heavens *beyond* Jupiter; but the earth *moves faster* than Jupiter, and at length *goes by him*, and as our globe seems stationary to us, Jupiter is seen to

What by its *apparent motions?* Why do the *apparent* motions differ so much from the *real* motions? What are the causes of the *apparent* motions? Explain why the *apparent* motions of Jupiter are at one time *direct* and at another *retrograde?*

move *backwards* among the stars from *east to west*, a direction contrary to that in which he is *actually advancing.*

627. Thus if two boats are sailing down a river, *one* of which is in the *middle*, and the *other* near the *shore;* if the *former sails faster* than the *latter*, a spectator upon the *first* will see the other boat *apparently* moving *up the stream*, though they are both *really* proceeding in the *same direction.*

628. THE PLANETS AT TIMES STATIONARY. We have just shown that in *one part* of a planet's orbit, its *apparent* motion is *direct*, and in another *retrograde.* There must accordingly be points in its orbit where its *apparent motion changes* from *direct* to *retrograde*, or the contrary; and at these points the planet must necessarily for a while appear *stationary.* Mercury is *stationary* at the distance of about 15° or 20° from the sun, and Venus at 29°.

CHAPTER VI.

COMETS.

629. COMETS are a class of bodies belonging to the solar system entirely different in appearance from any we have yet considered. The orbits in which they revolve are so elliptical, that during the greater part of their circuit they are *invisible*, being only detected when near the sun.

630. CONSTITUTION. The *comet*, when entire, consists of *three parts;* the HEAD, or NUCLEUS—the COMA, or ENVELOPE, and the TAIL. The *head* is nearest to the sun, and appears as a bright spot more *dense* than the other portions; but whether it consist of *solid matter*, like a planet is yet undetermined, for no telescope has

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Give the illustration in respect to the retrograde motion? Explain why the planets are at times *stationary?* At what angular distance from the sun is Mercury stationary? At what distance Venus? What does Chapter VI. treat of? What is said respecting these bodies? Of how many parts does a comet consist?

ever yet revealed a *true round disk* in any comet. Surrounding the head, but yet perhaps separated from it, is the *coma* which is a luminous fog-like covering that probably conceals from our view the real body of the comet. This envelope is conceived to give to comets a *hairy appearance*, hence their name.[1]

631. The *tail* is an expansion of the *coma*, the light matter of which streaming backward on either side in a direction *opposite* to the sun, diffuses itself for the most part into *two broad trains* of light, extending to an *immense distance*, and which constitute the *tail*. These streams sometimes unite at a short distance behind the *head*, and at others continue distinct throughout most of their length. All comets do not possess tails, even some of the most conspicuous present to view tails of only moderate dimensions, while others are as perfectly free from them as a planet. On the other hand, in a few instances, the tail has been divided into more than two streams, as in the case of the comet of 1744, when this extraordinary appendage was seen spreading out like a fan into *six magnificent trains.*

632. The *tails* of comets are often *curved outward* in the direction in which the body is proceeding. These appendages increase in *length* and *splendor* as they approach the sun until they are lost from view in his brilliant rays. Upon emerging into sight on the other side of the sun, the comet attains its greatest brightness, and the tail, now extended to its utmost limit, shines forth in full splendor. As the comet departs from the sun, the tail gradually loses its radiance, and decreases in length till it is absorbed in the head.

633. In Fig. 78, where the comet of 1819, is delineated, its *three* distinct parts are easily recognized.

634. NUMBER OF COMETS. This class of celestial bodies is without doubt very numerous, for, according to Sir John Herschel, the list of those on record before the invention of the telescope amounts to *several hundred.*

1. *Comet* from the Greek *komë*, signifying *hair.*

Describe each of them in full? Do all comets possess tails or trains? Does a comet ever have more than one? State the changes to which these appendages are subject? What is said respecting the number of comets on record before the telescope was invented?

FIG 78.

COMET OF 1819.

The *telescope* has added materially to this number, for not a year passes without some being brought to light from the depths of that obscurity in which they must have forever remained, if the astronomer had continued to gaze upon the heavens with his unaided eye. Within the last century, more than 140 comets have been seen which have not yet made their *second* appearance.

635. *Thirty comets* are known to have their *perihelion distances within the orbit of Mercury*, and M. Arago basing his calculations upon this fact, and also upon the supposition that comets are uniformly distributed through space, has computed that 3,529,470 comets have their *perihelion distances within the orbit of Uranus.* Moreover since comets may come within the limits of our solar system and yet be *invisible* to us, even with the telescope in consequence of *daylight*, the prevalence of *fogs* and *clouds*, and also from their being within the *circle of perpetual occultation*, M. Arago has considered, that he might safely estimate the number of comets within the orbit of Uranus at 7,000,000. If this calculation is extended

Has this instrument aided astronomers very much in this field of research? How many have been noticed within the last century which have not made their second appearance? State Arago's computation of the number of comets? Extend this computation to the orbit of Neptune?

as far as Neptune, the number of comets whose *perihelion distances* are within the orbit of this planet would amount to more than 28,000,000.

636. SPLENDOR AND SIZE. Comets *vary* much in respect to their *brilliancy* and *magnitude;* for while multitudes are only visible through the telescope, many of which are destitute of tails and heads, appearing only as *cloudy star;* others almost dazzle the gaze with their brightness, and extend their bright tails half across the heavens. Some comets have been seen of such surpassing splendor that they were visible in *clear daylight,* such were the comets of 1402 and 1532, and also that of 1843.

637. The famous comet of 1680 was conspicuous for the great length of its tail; for soon after its nearest approach to the sun, this wondrous appendage shot out from the body of the comet to the distance of 60,000,000 miles, and in the incredible short space of *two days.* When it had attained its *greatest length* it extended no less than 123,000,000 miles from the head, covering a space in the heavens greater than the distance from the *horizon* to the *zenith.* The comet of 1811, had a nucleus only 428 miles in diameter, while the tail stretched out to the distance of 108,000,000 miles. The *diameter* of the envelope of the comet of 1843, was 36,000 miles, and the *greatest length* of the train 108,000,000 miles, a length more than 4000 *times* the circumference of the earth.

638. VELOCITY. Comets when *nearest* the sun, move with incredible speed, that of 1680, is said to have gone half around the sun, in *ten* and a *half* hours, moving with the speed of 880,000 miles an hour, or more than 645 *times faster* than a cannon ball. The comet of 1843, sweeping more than half around the sun in *two and a half hours* moved with a velocity of 1,300,000 miles an hour, or one forty fourth as fast as a message is transmitted through the wires of the telegraph. As these

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State what is said in regard to the *splendor* and *size* of these bodies? State what is here said of the several magnitudes of the comets of 1680, 1811, and 1843? What is remarked of the *velocity* of comets when *nearest* the sun? Give an account of the speed of the comet of 1680, and of that of 1843? What is said respecting the *velocity* of a comet as it *departs* from the sun?

bodies depart from the sun, their velocity *decreases*, according to the laws of attraction already explained, (Art. 405,) and to describe those portions of their respective orbits that are remote from the sun, requires periods of time, varying from a *few years* to *many hundreds.*

639. TEMPERATURE. The *temperature* of comets depends upon their proximity to the sun, since like the planets they derive their light and heat from this source. The comets most remarkable for their close approach to the sun are those just mentioned; viz., the comets of 1680 and 1843. The *first* was only 147,000 miles from the surface of the sun, and was exposed to a heat 27,500 times greater than that received by the earth in the same time—a heat 2,000 times *greater than that of red-hot iron* and sufficient to turn into vapor every known terrestrial substance. At this distance the sun, as it would have appeared from the comet, must have had an *apparent diameter* more than 140 times greater than it has at the earth, and would have covered a space in the heavens extending from the *horizon* to near the *zenith.*

640. The comet of 1843, came within about 60,000 miles of the sun's surface; so near in comparison with the immense distance it recedes from the sun that it is said to have almost *grazed* it. The sun as viewed from this comet at its *perihelion* would have had an *apparent diameter* of 121° 32′, and its disk would have appeared *forty-seven thousand* times larger than it does at the earth.

641. According to Sir John Herschel, the heat it received from the sun was 47,000 times greater than that which falls upon the earth in the same time, when the sun is shining perpendicularly upon it. So *intense* is such a heat that it is 24½ times greater than that which is sufficient to *melt agate*, and *rock crystal.* The comet even for some days after it passed its *perihelion*, presented a *glowing appearance*, being in fact *red-hot.*

642. COMETS SHINE BY REFLECTED LIGHT. This fact is proved in the following manner, when *a self-luminous*

From what source do these bodies derive their *light and heat?* What comets are remarkable for their near approach to the sun? How near did the comet of 1680 approach the surface of the sun? How hot was it? Why was it so hot? How large would the sun appear if viewed at the *perihelion distance* of this comet? State the like particulars respecting the comet of 1843?

body, as a lamp for instance, is carried gradually away from us, the *size of the flame* grows smaller as the distance increases, while the *brightness is the same* at all distances. But if a body which shines by *reflected light* is thus withdrawn, it grows *fainter* and *fainter*, until at last it *vanishes.*

643. Now when comets are subjected to this test, it is found that their *brightness* is *not* the *same* at all distances, but that it gradually diminishes as they recede from us. These bodies shine then by *reflected light*, the bright beams of the sun reflected from their diffused atoms of matter, causing the enormous volume of the comet to glow with light; in the same manner as the flying vapors that float in our atmosphere become radiant throughout their whole depths, with the reflected solar beams.

644. ORBITS—PERIHELION DISTANCES. The *orbits* of comets for the most part are *ellipses*, with the sun in their *common focus;* but unlike those of the planets which deviate but little from a circle in form, the elliptical orbits of comets are exceedingly *elongated*, their *major axes* (Art. 16,) running out to almost an infinite length.

645. In consequence of this extended form of the orbit, the comet is only beheld for a short time while it is *near the sun;* after which it occupies *years* and even *centuries* in accomplishing the remainder of its circuit—sweeping far beyond the limits of the planetary system where no telescope can begin to descry it.

646. The *perihelion distances* of these bodies are very various,[1] 30 are found to approach nearer the sun than Mercury, and most of those visible from the earth have swept nearer to the sun than Mars. Others have doubtless their perihelion distances far more remote, but are unseen by us on account of their great distances. In a very few instances comets have been known to move in *hyperbolas*, a *curve* that does *not return into itself;*[2] These

1. See Figure 1, page 16.

2. A *curve is said to return into itself*, when a body starting from *any point* of it, and moving along it, at last comes round to the *same*

Do comets shine by their own or by reflected light? Prove it? State what is said respecting the *orbits of comets* and their *perihelion distances?*

therefore sweeping around the sun can never again revisit us while the nature of their path remains unchanged; but speed away to unknown systems, or wander through the limitless regions of space, till they come within the influence of some vast orb strong enough to control their roving propensities.

647. INCLINATION OF THEIR ORBITS—DIRECTION OF MOTION. The orbits of comets differ also from those of the planets in respect to *position;* for while those of the latter have in general but a small inclination to the plane of the ecliptic, the orbits of the former cut it at *all angles*, being sometimes nearly perpendicular to it. Neither have comets like the planets a common motion from *west* to *east*, but they traverse the heavens in all directions, subject to no law in this particular.

648. Out of nearly 200 comets whose respective directions are known, about one-half have a *retrograde*, and the other a *direct motion.*

649. ELEMENTS—IDENTITY. *Three* good observations of the *right ascension* and *declination* of a comet, together with the times at which they were made, are sufficient to enable the astronomer to calculate the *elements* of its orbit.[1] Of all the comets that have been

point again. Such *curves* are the *circle* and *ellipse.* The curve of the *hyperbola* is shown in the annexed Figure, B is the *vertex* of the curve,

and from this point it stretches away in two branches BA and BC to an infinite length, the branches continually diverging from each other. A body moving along this curve from any point of it can therefore never return to the place whence it started. This curve *does not return into itself.*

1. The *elements* of a comet's orbit are,
   1. *The longitude of the perihelion.*
   2. *The longitude of the ascending node.*
   3. *The inclination of the plane of its orbit to that of the ecliptic.*

What of the *inclination of their orbits* and *direction of motion?* *How many* and *what observations* will enable an astronomer to compute the elements of a comet's orbit?

observed the orbits of about 190 have been determined, and out of all these, the return of only *four* have been verified by observation; namely, Halley's, Encke's, Biela's, and Faye's.

650. The *identity* of a comet upon its return is established by the *identity of its elements*, and not by its physical appearance, for this is subject to change; the body presenting great modifications in this respect upon its successive returns.

651. HALLEY'S COMET. Edmund Halley, a celebrated English astronomer, upon calculating the elements of different comets, discovered that the elements of the comets of 1531, 1607, and 1682 were *identical.* He therefore concluded that these three comets, so called, were actually one and the same body, which revisited the earth at these epochs. The interval between 1531, and 1607, being 76 years, and that between 1607 and 1682, being 75 years, he ventured to foretell that the comet would reappear in nearly 75 or 76 years from the last date, and accordingly predicted its return about the year 1759.

652. Clairaut, an eminent French mathematician, after calculating the amount of the influence of Saturn and Jupiter in retarding the appearance of the comet, fixed the time of its return to its perihelion, within a month, one way or the other, of the middle of April, 1759. It came on the 12th of March in that year.

653. In the year 1835 it again returned, passing its perihelion within *one day* of the time calculated by Pontecoulant, a French astronomer. So *vast* and *eccentric* is the orbit described by this comet, that while its *perihelion distance* is 57,000,000 miles, its *aphelion distance* is 3,420,000,000 miles, a point in space *more remote* than that of Neptune, by 600,000,000 miles.

654. Halley's comet had been observed and its pecu-

4. *The eccentricity of the orbit.*
5. *The length of the semi-major axis of the orbit*
6. *The time of passing the perihelion.*
7. *Motion, whether direct or retrograde.*

Of how many have the orbits been computed? What number of comets have had their returns verified by observation? Mention them? How is the identity of a comet established? Give the full account of Halley's comet?

liarities recorded *four times* before its appearance in 1682. In 1305, it is described by the writers of that age as a comet of a dreadful size. In 1456, its train extended through the heavens for the space of 90°, stretching from the horizon to the zenith, and filled all Europe with such terror that, by the decree of the Pope, prayers were offered in all the Catholic churches, and the bells rung at midday in order to avert the wrath of heaven. In 1682, the tail was only 30° in length; in 1759, it had so diminished in size that it was not visible to the naked eye until it had passed its perihelion, while in 1835 its tail was about 20° in length.

655. Encke's Comet. This comet receives its name from Prof. Encke, of Berlin, who first ascertained that it returned at stated times, in the short *period* of 1,211 days, or about $3\frac{1}{3}$ *years.* Prof. Encke made this discovery upon its *fourth* recorded appearance in 1819, and predicted its return in 1822. It came at the appointed time, and from that year forward it has returned at its regular intervals, obeying the same law of gravitation that controls the earth in her orbit.

656. Biela's Comet. This is another small cometary body which revolves about the sun in the period of 2,410 days, or about $6\frac{3}{4}$ years. This discovery was made by Mr. Biela, of Josephstadt, in the year 1826, who predicted the return of the comet in 1832. The prediction was *fulfilled.* In 1839, its position was very unfavorable for observation, and there is no record of its having been observed at all at this time.

657. Upon its return in the year 1846, this body was most surprisingly modified, for instead of one comet it was separated into *two bodies*, each having the true characteristics of a comet. These *twin* bodies, which were termed the *comet* and its *companion*, passed along through the heavens side by side for the space of 70°, changing in their relative brightness and magnitude, and also in their distances from each other.

658. According to Mr. Plantamour of Geneva, the distance between the *nucleus* of the *comet*, and *that* of its

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Give the full account of Encke's, of Biela's?

companion, during the time of their visibility varied from 149,000 miles to 154,000 miles.

659. Faye's Comet. Mr. Faye, of the Observatory of Paris, discovered on the 22d of November, 1843, a telescopic comet, which on the 27th of December, was *rediscovered* in this country by Mr. Joseph S. Hubbard at New Haven. It had a *bright nucleus* and *fan-like tail.* It was found to revolve about the sun in an elliptical orbit, in the space of 2,718 days, or a little less than 7½ years.

660. The return of the comet to its perihelion was predicted within a day or two of the 3rd of April, 1851. It was seen by Prof. Challis, of Cambridge, England, on the 28th of November, 1850, and was observed by him until the 4th of March, 1851.

661. De Vico's Comet. This comet, which was discovered by De Vico, director of the observatory at Rome, on the 22d of August, 1844, possesses a *brilliant nucleus* and *small tail* and when most vivid is visible to the naked eye. The calculations of several astronomers soon showed that it revolved in an elliptical orbit, and that the period of revolution was 1,990 days, or nearly 5½ years.

662. The date assigned for its return was about the 13th of January, 1850, but there is no record of its reappearance at that time.

663. Comet of 1680. This remarkable comet, whose surpassing size and splendor we have already alluded to, is supposed with great probability to revolve about the sun in the long period of 575 years.

664. It is regarded as identical with a vast and brilliant comet which was beheld at Constantinople, in the year 1105, A.D., with one that was seen *close to the sun* in the year 575 A.D., with a third which appeared near the time of the assassination of Julius Cæsar, in the year 43 B.C.: and lastly, with *two others* mentioned in the Sybilline Oracles, and in Homer, which according to the most reliable calculations were visible in the years 618, and 1194 B.C.

Give the full account of Faye's and of De Vico's? State what is further said of the comet of 1680?

665. Comet of 1843. We have already stated many particulars respecting this most extraordinary body, but a further description is by no means superfluous. It was seen on the 28th of February, 1843, *close to the sun*, its brightness being so great that the splendor of the solar beams could not overpower its brilliancy.

666. "In New England," says Professor Loomis "it was beheld from half past 7 A.M., till 3 P.M., when the sky became considerably obscured by clouds. The appearance was that of a *luminous globular* body; the *head* of the comet, as observed by the naked eye appearing *circular;* its light equal to that of the moon at midnight in a clear sky, and its apparent size about $\frac{1}{8}$th the area of the full moon."

667. At the Cape of Good Hope, it was seen by every person on board the Owen Glendower, on the day just mentioned, at about *sunset*, near the sun, and having the *shape of a dagger.*

668. The vast extent of the tail has already been stated. At the Cape of Good Hope, it appeared on the 3rd of March to be *double*, *two trains* diverging from the head in a straight line, forming a small angle with each other. Near the *equator* this magnificent appendage shone with such a glow that at times it threw a bright light upon the sea. The comet remained visible only for a short time, the *earliest* observation upon it appears to have been made on the 27th of February, and the *latest* on the 15th of April.

669. The elements of this comet are not yet decidedly ascertained. A brilliant comet appeared in 1668, the head of which was concealed by the splendor of the solar rays, and whose tail, extending to an immense distance, was so vivid that its image was reflected from the surface of the sea. The investigations of astronomers point in their results to an identity between the comets of 1668 and 1843; inasmuch as on the whole, they present nearly *similar aspects*, pursue nearly the *same path*, and the period of revolution assigned to each is 175 years. Prof. Hubbard, of the Washington Observatory, finds however, from a rigorous discussion

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Describe in full the comet of 1843?

of all the observations made on the comet of 1843, that it most probably revolves in an elliptical orbit, in a period of about 170 years.

670. Physical nature of Comets. These extraordinary bodies consist of *matter*, but existing in an attenuated and diffused state, of which we have no adequate conception. That they *consist of matter* is proved by the fact that they *revolve* in regular orbits around the sun, obeying the same law of attraction as the solid masses of the *planets*; and that this matter is extremely rare and subtile, is shown by the circumstance that the *smallest stars* are *visible* through the tail of a comet.

671. A light cloud, in comparison with the matter composing the *tail of a comet*, is to be regarded as a *dense* and *heavy* body. For while the *former*, though *gauze-like* in its *texture* and of *moderate* thickness is yet sufficiently dense to obscure the light of a star; the *latter*, notwithstanding it is *millions of miles* in extent, permits the stellar rays to traverse its vast thickness, and to reach the eye, distinctly revealing the orb from which they emanate.

672. The *amount of matter* in comets, even of the *largest size*, is so *small* that their passage around the sun has never in the least perceptible degree affected the *stability of the solar system*; in other words, they have never, as far as could be perceived, caused the planets to deviate a hair's breadth from their accustomed paths around the sun.

673. According to the celebrated La Place, if the *mass* of the comet of 1770, which passed within 1,500,000 miles of our globe, had been *equal* to that of the earth, it would have increased our *sidereal year* by 2h. 53′. But the profound investigations of Delambre, showed that the length of the year was not increased by the fraction of a second, and that consequently the *mass* of the *comet*, could not have been equal to *one-five thousandth part* of the mass of the earth.

674. Collision with the Earth. Fears have often

State what is said respecting the physical nature of comets? Show that the matter of comets must be very much attenuated? Why must their *amount* of matter be small? Give the proof?

been entertained that collisions might occur between the earth and comets. When any one of these bodies has its *perihelion* within the orbit of Mercury it must necessarily cross the orbits of all the planets, and such a collision may *possibly* take place, but the *probability* is exceedingly small.

675. Upon the supposition that *the nucleus* of a comet, possesses a diameter one-fourth the size of that of the earth, and that its perihelion is within the earth's orbit, Arago has computed the chance of our meeting the comet to be as 1 to 281,000,000.

676. But were the earth to meet a comet, it would be somewhat like a *cannon ball* meeting a *cloud*, and the earth would probably suffer but little from the encounter. Indeed, it has been supposed by some, that we have *already passed through the tail of a comet* without knowing it, for, according to Mrs. Somerville, there is reason to think that such was the case when the great comet of 1843, revealed its splendors to our eyes.

CHAPTER VII.

TIDES.

677. THE *periodical rising and falling of the waters of the ocean in alternate succession are called tides.* Standing on the sea shore, a person will perceive that for the space of nearly 6 *hours* the waters of the sea continue to rise higher and higher, overflowing the shores, and running into the channels of the rivers. When they have attained their greatest elevation, it is then said to be *high tide*, *full sea*, or *flood tide.* Remaining at this elevation only for a few moments they then begin to fall, and continue to sink for about 6 *hours more.* When the waters have reached their *greatest depression*, it is then *low*, or *ebb tide.* After attaining this point, the sea in a short time again

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Is it *possible* for a comet to strike the earth? Is it *probable?* What effect would a collision with a comet probably have upon the earth? May we have already passed through the tail of a comet? What does Chapter VII. treat of? What are the tides? Describe them, explaining the meaning of *high tide* and *low tide?*

begins to *swell* in the same manner as before, and thus from *year* to *year*, and from *century* to *century*, the *ebb* and *flow* of the ocean follow each other at regular intervals of time.

678. From the above explanation it will be seen that there are *daily two high tides* and *two low tides* The *interval of time* between two successive high or low tides, is about 12h. 25m. Accordingly when there is a high tide at any place, as New York, for instance, there must also be a high tide on the *opposite side* of the globe, and the same is true in respect to a *low tide*. These points are illustrated in Fig. 79, where O and O¹ represent the places where the *high tides*, and B and C, those where the *low tides simultaneously* occur on the globe.

FIG. 79

HIGH AND LOW TIDES

679. A marked correspondence exists between the *motion of the tides* and the *motion of the moon*. If *to-day* at 10 A. M., it is high tide in a certain harbor, it will be high tide *to morrow* in the same harbor at 10h. 50m. 28sec. A. M. The interval therefore that elapses between any *high tide* and the *next but one* after it, is 24h. 50m. 28sec. Now this is the *exact* amount of *time* that intervenes between two successive passages of the moon over the *meridian* of any place. In fact as the earth revolves on her axis, the *tide wave* tends to keep *under the moon*, and thus sweeps around the globe from any port to the same port again, in the precise period of time that

How many *high tides* and *low tides* occur *daily*? What is the interval of time between two successive high or low tides? When a high tide for instance occurs at any port where is there then also *another* high tide? Explain the Figure. What marked correspondence is here alluded to? Describe it particularly?

elapses between two *successive returns* of the *moon* to the *meridian* of this port.

680. CAUSE OF THE TIDES. *The* UNEQUAL *attraction exerted by the sun and moon upon different parts of the globe produces the tides*, and we will now proceed to explain this phenomenon, commencing with the moon. In Fig. 79, let M represent the moon, E the *solid portion of the earth*, and CDOFB and $CD^1O^1F^1B$ the *ocean*. Now every particle of matter belonging to the globe is attracted by the moon, with a force which *varies inversely with the square of the distance of the particle from the centre of the moon.*[1] It is evident, that under the influence of this varying force, the solid portion of the globe will remain imperceptibly *unchanged in form*, because the *atoms* that compose it, are bound together in a *mass*, and if one particle moves all the rest move with it. But the *watery atoms move freely*, and are influenced by the slightest variation in the *lunar attraction;* accordingly the moon tends to produce high tides *directly beneath* her as at O and O^1, and low tides *half way* between these points as at B and C.

681. WHY HIGH TIDES OCCUR ON OPPOSITE SIDES OF THE GLOBE. The waters of the globe, as represented in the figure, assume the form they possess under the action of *two forces; First*, the *force of gravitation* by which they tend towards the earth's centre; *Secondly*, the *attractive force of the moon*, by which they tend to move toward the moon's centre. Now on the side of the earth toward the moon, the waters about O are drawn in *one direction* by the *lunar*, and in the *opposite* by the *terrestrial attraction;* but being *nearer to the moon* than the rest of the waters belonging to *the hemisphere* BOC they are consequently *most attracted* by this body, and by the influence of this *excess of attraction* are compelled to *swell outwards* towards the moon. Thus the waters in the vicinity of O have their *gravity towards the centre of the earth diminished* by the disturbing action of

1. See Art. 405.

What is the *cause of the tides?* Explain from Figure 79, the action of the moon in producing tides? Explain in full how high tides are produced on *opposite* sides of the globe?

the moon, and to restore their equilibrium, they here accumulate.

682. The waters about O^1, in the hemisphere BO^1C are *less attracted* by the moon than on any other part of the ocean on the *entire globe;* because they are the *most distant* from this luminary, and the attraction is here below its average value. Now as the moon's attraction at O^1 is *directed towards the earth's centre* a *deficiency* of lunar attraction at O^1, necessarily *diminishes the gravity* of the waters about O.[1] They are consequently *heaped up* at this point, just as in the former case, and the elevated surface of the sea assumes an *oval form.*

683. WHY LOW TIDES OCCUR ON OPPOSITE SIDES OF THE GLOBE. At the places B and C, the action of the moon is *oblique* to the surface of the ocean, and it is evident that if any particle of water at B, is drawn by the lunar force in the direction BM, it will not only approach the *centre of the moon* but also the *centre of the earth.*[1] Now that part of the *lunar force* which produces this *latter* motion, acting upon the waters in the *direction of terrestrial gravity*, and *in addition* to it, necessarily depresses them *more* than usual; they accordingly fall, in order to regain their equilibrium, and the surface of the ocean becomes *flattened* at B and at C.

At O then the *excess* of the *direct action* of the moon *raises* the *waters of the sea*, and at O^1 a *deficiency* of this *direct action* produces the same effect; while at 90° degrees distance from these points; viz., at B and C her *oblique* action *depresses* them.

684. As we advance from B or C towards O, in the *hemisphere* BOC, the action of the moon becomes *less and less oblique* to the surface of the sea, and her power to *depress* it and *increase the gravity* of the waters *gradually diminishes. At the distance of* 35° from B and C, to wit, at F and D, this power *vanishes*, and upon *passing this*

1. That a force *acting obliquely* upon a body, tends to produce motion in *two directions* is a well known fact. Take for instance the case of a boat sailing *obliquely* across a stream. Here the force of the wind carries the boat in *two directions* from its starting point at the same time; viz., *across* the river and *along* the bank.

Explain how two low tides are produced on opposite sides of the globe?

limit the force of the moon tends to *elevate* the waters of the globe.

685. In the *opposite hemisphere* BO^1C a similar effect is produced. At the distance of 35° degrees from B and C; viz., at F^1 and D^1, the moon *ceases to increase* the gravity of the waters, in the directions BE and CE, while those that occupy the remaining part of this hemisphere; that is, $F^1O^1D^1$, are drawn towards the moon, but with varying force, according to their respective distances from this body. Thus the *waters at* F^1 *and* D^1 will be drawn toward the moon and the solid part of the earth with *more power* than the *waters at* O^1; the *latter*, therefore, will virtually rise in respect to the *former*, and under this varying force the surface of the sea throughout the space $F^1O^1D^1$ will assume an *oval shape.*

686. In fine, we may say, that the equilibrium of the waters of the ocean is disturbed by the action of the moon, and is not restored until they assume, under this action, the oval or ellipsoidal form in the manner described.

687. Solar Influence. The *sun* like the moon produces tides by the *unequal* attraction it exerts upon the waters of the ocean, causing *high tides* at the points immediately beneath it on *opposite sides* of the globe, as at O and O^1, and *low tides* at 90° distance from these points, as at B and C. The sun's influence is however only about *one-third* of that of the moon, notwithstanding its vast superiority in size and mass. But any difficulty that may arise in understanding this fact will vanish, when we reflect that it is the *unequal action* of these bodies upon the waters of the earth that produces the tides, and not their *whole attraction.* Now the waters at O, Fig. 80, are about 8,000 miles (the earth's diameter) *nearer* the sun and moon than the waters at O^1, but 8,000 miles is $\frac{1}{30}$th part of the moon's distance from the *earth* while it is only $\frac{1}{12000}$th part of the sun's distance[1] from the *earth.*

1. The moon's distance from the earth is about 240.000 miles, which being divided by 8,000 miles, the quotient is 30. 8,000 miles is therefore $\frac{1}{30}$th

To what extent around B and C are the waters of the ocean *depressed* by the action of the moon, and to what extent *elevated* about O and O^1? What is said respecting the sun's influence in producing tides? What is said of the amount of solar influence? Explain why it is small?

688. We thus see that the attraction of the moon upon the waters of the opposite hemispheres is manifestly *unequal*, while that of the sun is almost *unchanged.* The investigations of philosophers have proved that while, by the *moon's* influence, the waters of the ocean at O and O′ are 58 *inches* higher than at B and C; the difference caused by the action of the sun is only 23 *inches.*

689. SPRING AND NEAP TIDES. We have just seen that the sun and moon cause tides in the ocean, *independently of each other.* These bodies however are perpetually *changing their relative positions* in the heavens, and on this account their separate actions are at alternate periods of time *united* and *opposed* to each other. The sun and moon act together *twice a month;* viz., at the *syzygies;*[2] and the tides are then unusually high, since the *lunar* and *solar* tide waves are then *heaped* one upon the other. These are the SPRING TIDES.

690. *Twice every month*, at the *quadratures*, the sun and moon *oppose* each other; for at those points on the earth's surface where the *sun's* action then tends to *elevate* the waters, the *moon's* influence *depresses* them, and where the *moon raises* the *surface* of the ocean, the influence of the sun is exerted to cause it to *sink.* These are the NEAP TIDES.

691. The entire *lunar tidal* fluctuation being about 5 feet and the *solar* 2, the *average heights* of the *spring* and *neap tides* will be in the ratio of 7 to 3. At the time of the *neap tides*, the *low tides* are *higher* than *ordinary*, since at the places where they occur the *solar tide wave* is at its *greatest altitude* and its height must be *added* to the height of the low water, caused by the moon's action. But the *high tides* are then unusually *low*, since the *lunar high tide wave* is *diminished* by the *solar low tide.*

692. In Figs. 80 and 81, the subject of the *spring tides*

part of the moon's distance from the earth. Calling the sun's distance from the earth in round numbers 96,000,000 miles, we find in the same way that 8,000 miles is about $\frac{1}{12000}$th part of the sun's distance from the earth.

1. The tidal influence of the sun and moon is found according to the law of *universal gravitation* to be *inversely as the cubes of their distances.*

2. See notes 1 and 2, page 148.

What have philosophers shown respecting the heights of the *solar* and *lunar tides?* When do the spring tides occur? When the neap tides?

FIG. 80.

SPRING TIDE—NEW MOON.

is illustrated. In each of these figures, S represents the *sun*, M the *moon*, and E the *solid portion of the earth.* The *dotted line* inclosing the earth is the *solar tide-wave*,

FIG. 81.

SPRING TIDE—FULL MOON.

and upon this in the line of the *three bodies*, is heaped the *lunar tide-wave*, the boundary of which is the *outer* curved line.

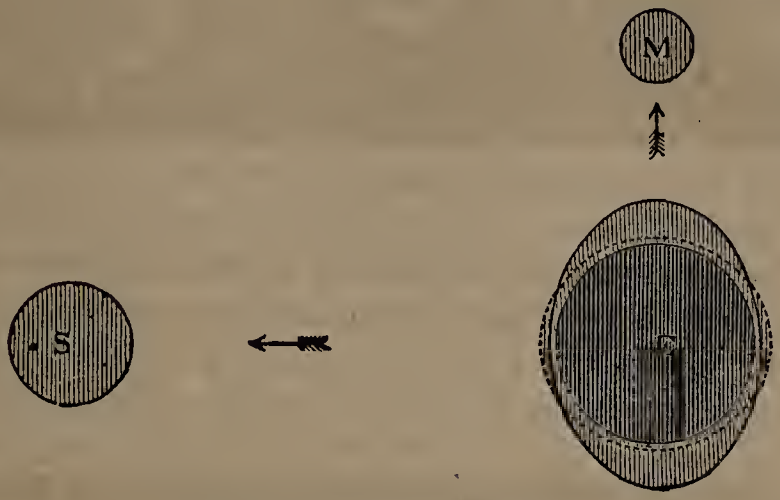
693. In Fig. 82, is exhibited the phenomenon of the *neap tides.* The moon is in *quadrature*, 90° from the sun, and the two bodies evidently *counteract* each other's influence in producing their respective tides. The solar tide wave, as in the preceding figure is represented by the *dotted oval line*, and the *lunar tide wave* by the *unbroken curved line.*

694. Since a difficulty is sometimes experienced in understanding how a spring tide is produced when the sun and moon are on opposite sides of the globe, we will explain this point a little more particularly. In Fig. 80, where the sun and moon are on the *same side* of the earth, it is the time of new moon, and a spring tide

Describe these phenomena in full, and explain from Figures 80, 81, and 82?

occurs. From the reasoning employed in Arts. 681–2, it will be perceived that the waters at O are heaped up by

FIG. 82.



NEAP TIDE—QUADRATURE.

the *excess of attraction* exerted by the *sun* and *moon*, to draw the waters from the centre of the earth, thus rendering them more convex than usual. Around O¹ there is a *deficiency of solar and lunar attraction*, and the waters in this region are drawn down less than usual toward the centre of the earth, and they are consequently higher than common.

695. In Fig. 81, the *sun and moon* are on *opposite sides* of the earth. The moon is at her *full*, and a spring tide now also occurs. At O the sun produces a high tide by his *excess of attraction* and the moon here causes a high tide by her *deficiency of attraction*, since that which is the *nearest* hemisphere to the *sun* is the *farthest* from the *moon*. At O¹ the moon's *excess of attraction* gives rise to the lunar high tide, while the sun's *deficiency of attraction* causes here likewise a *solar high tide;* for in this case the *hemisphere* which is *nearest to the moon* is the *most remote* from the *sun*.

696. TIME OF THE TIDE. In Art. 679, we have said that there exists a marked correspondence between the motions of the tide, and those of the *moon*. If the waters moved with perfect freedom, the *lunar tide wave* would

Show why a *spring tide* occurs at *full moon* ?

be *highest* at any place when the *moon* was upon the *meridian* of the place; and the *solar tide wave highest* when the *sun* was upon its *meridian*. But the waters do not at *once obey* the action of the sun and moon, on account of their inertia; and they are also retarded in their motion by the *friction* produced in their passage over the *bed of the sea* and the *sides* and *bottoms* of *channels*. It thus happens that the high tide does not occur at any place until the moon has passed its meridian several hours.[1] The *interval* between high tide and the moon's *meridian* passage is however not constant, but varies in different places.

697. PRIMING OR LAGGING OF THE TIDE. The *actual* high tide at any part is produced by the *union* or *superposition* of the *solar* and *lunar* tide waves. Now on account of the *changing relative positions* of the sun and moon, these waves do not so unite as to make the high tides recur at any port at the expiration of exactly equal intervals of time. The tide days therefore, are not of the uniform *length* of 24h. 50m. 28sec., but vary somewhat in duration, and this variation is quite marked about the time of the new and full moon.

698. EFFECT OF DECLINATION ON THE HEIGHT OF THE TIDE. The highest point of the tide wave, tends to place itself directly beneath the body which raises it, so as to be exactly in the line joining the centres of this body and of the earth. If therefore the sun and moon were always found in the plane of the equator, the tides would be *highest* in the *equatorial regions*, while a *constant low tide* would exist at the *poles*. But these luminaries are not thus situated, since, owing to the obliquity of the ecliptic, they have an apparent motion north and south of the equator; the sun departing from the

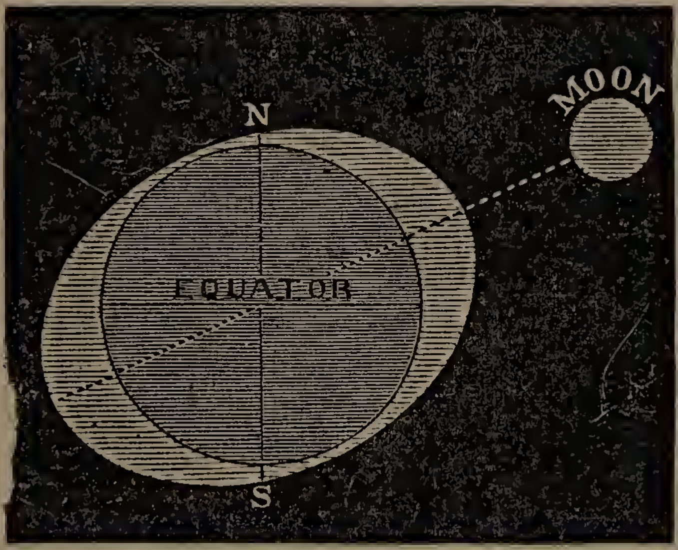
1. At Dunkirk, for instance, high water occurs *half a day* after the moon passes its meridian, at St. Malo's *six hours*, and at the Cape of Good Hope, *one and a half hours*.

Why does not the high tide occur at any place when the moon is exactly on its meridian? How long a period sometimes elapses after the moon has passed the meridian *before* the high tide happens? Is the interval between the *time* of high tide at any place, and the moon's meridian passage, invariably the same? Explain what is meant by the *priming* and *lagging* of the tide? Are the *tide days* of uniform length? When is the variation greatest? Why do the declinations of the sun and moon influence the tides?

equator about $23\frac{1}{2}$ degrees, while the moon attains a declination of 29° on one side, and about 17° on the other.

699. These changes in the position of the *sun* or *moon* accordingly affect the height of the tide at any particular place. When the moon, for example, has her greatest northern declination, the *daily* high tides will be *highest* in all those places in the *northern hemisphere* where the moon is *above* the *horizon*, and *lowest* where she is *below* the *horizon*. In the *southern hemisphere* the phenomena are reversed; the daily *high tides* being *highest* at all those places where the moon is *beneath* the *horizon*, and *lowest* in all the *regions* where she is above the *horizon*. A glance at Fig. 83, proves these statements.

FIG. 83.



700. Actual heights of the Tide. The *theoretical height* of the tide does not correspond to the *real height*. This difference is owing to *local causes*, such as the union of two tides or the rushing of the tide wave into a *narrow channel*. In the latter case the advance of the tide is often very rapid, and the water rises to a great elevation. Thus within the British Channel, the sea is so compressed that the tide rises 50 feet at St. Malo's, on the coast of France. In the Bay of Fundy, the tide swells to the height of 60 or 70 feet. Here, according to Prof.

State why these changes in the position of the *sun* or *moon* affect the height of the *tide* at any particular place? Why does not the *theoretical* height of the tide at any place correspond with the *actual* height?

Whewell, the tide wave of the South Atlantic, meets the tide wave of the Northern Ocean, and their union raises the surface of the sea to the height just mentioned. On the vast Pacific, where the great tide wave moves without obstruction, the rise of the water is only about *two feet* on the shores of some of the South Sea Islands.

701. DERIVATIVE TIDES. The tides perceptible in rivers, and in seas communicating with the ocean, are termed *derivative tides;* inasmuch as they are not produced by the *immediate action* of the sun and moon, but are portions of the great *oceanic tide waves*, which flow in from the *open sea.*

702. The *derivative tides* ascend the large rivers of the globe to a great distance from their mouths; but their upward progress is so much retarded by their friction against the banks, and the various impediments they encounter, that several tides in some instances are found at the *same time* along the same river. Thus, at the Straits of Pauxis, in the Amazon, *five hundred miles* from its mouth, the tide is distinctly perceptible; and so much is it retarded in ascending this mighty stream, that at the time of the equinoxes, for *three successive days*, *five tide* waves, rising to the height of from 12 to 15 feet, follow each other *daily* up the river.

703. NO TIDES EXCEPT ON THE OCEAN, AND ON SEAS CONNECTED WITH IT. *Inland seas* and *lakes* have no perceptible tides. None have ever been observed in the Caspian sea, or in any of the great North American Lakes. This is owing to the fact that the attractive forces exerted by the moon upon the waters of a lake are so *nearly* the same in every part, that no *sensible difference* can exist; and as the tides are caused by the differences that occur in the *amount* of attraction, it follows that where there is *no difference* there is *no tide.* These remarks apply with greater force to the attraction of the sun. It is only in the ocean that the expanse of water is sufficiently great to cause such an inequality of action, both in the *lunar and solar* attraction, as to produce tides. Of

State the cases cited ? Explain derivative tides ? State what is said respecting *derivative tides* ascending long rivers ? Give the facts in regard to the Amazon ? Have tides been noticed in *lakes* and *inland seas ?* Why do they not occur in such waters ?

course *inland seas* and lakes can have no *derivative tides.*

704. In the Mediterranean and Black Seas, which are almost entirely encircled by land, the tides are scarcely *perceptible.*

705. The *atmosphere* like the *ocean* must have its *tides*, but they are so exceedingly minute in extent that it is barely possible to detect them. Col. Sabine, from daily barometrical observations at St. Helena, succeeded in discovering, that on an average the mercury in the instrument was *one-four thousandth of an inch higher* at the time the *moon crossed the meridian*, either *above* or *below* the *horizon*, than when she was *midway* between these *limits.*

706. In the other planets of the solar system, that are attended by *moons*, *tides* must also exist, if their *orbs* are *covered* by *oceans* and enveloped in *atmospheres.* The phenomenon we have been considering is therefore not necessarily confined to the earth.

CHAPTER VIII.

TERRESTRIAL LONGITUDE.

707. In order to determine the precise situation of a place on land, or a ship at sea, their respective *latitudes* and *longitudes* must be known, (Art. 58.) It is of the utmost importance to mankind that these measurements should be ascertained with great accuracy, especially on the *ocean*, in order that the mariner may know his *exact position* in the midst of dangers, that threaten the lives and property entrusted to his care.

708. *Latitude* has already been explained and one method given by which it can be obtained, (Art. 57;) we shall now speak of *longitude* and briefly unfold the several methods by which it is determined. This prob-

What is said of the tides in the Mediterranean and Black Seas? Has the atmosphere tides? State the observations of Col. Sabine? May other members of the solar system possibly have tides? What is the subject of Chapter VIII.? How is the exact position of any place on *land* or *sea* ascertained? Why is it important to mankind that these measurements should be *precisely* determined?

lem is intimately connected with *astronomy;* inasmuch as *eclipses* and the *motions* of the *moon* afford methods most highly prized and extensively employed for ascertaining the longitude. On this account the subject of longitude was not introduced in connection with latitude, but was deferred until the lunar motions and the phenomena of eclipses in general had been discussed.

709. LONGITUDE. *The longitude of any place is its distance east or west of a given meridian, measured in degrees, minutes, and seconds.* It can be ascertained by *four methods;* 1st. *By chronometers*[1]; 2nd. *By means of eclipses;* 3d. *By the electric telegraph;* 4th. *By the lunar method.*

710. BY CHRONOMETERS. Supposing, for example, that it is now 12 o'clock at Greenwich, the sun being there on the meridian, it is evident that at any place 15° *east* of Greenwich, it must at this instant be 1 o'clock; (Art. 104,) because this place, owing to the rotation of the earth, was in the *same position* in respect to the sun *an hour ago*, as Greenwich now is. Moreover, at a place 15° *west* of Greenwich it is now 11 *o'clock*, because the sun will not be on the meridian of this place until an *hour after* it is noon at Greenwich. The *local time* of the first station will accordingly be *faster* than Greenwich time by *one hour*, and that of the second *slower* by the *same quantity.*

711. Now if a person were to travel around the globe from *east* to *west* or from *west* to *east*, with a chronometer that kept true Greenwich time; he could readily ascertain the *longitudes* of each of the several places where he arrived, reckoning from the meridian of Greenwich, by finding the *difference* between their *respective local times* and the *Greenwich time*, as indicated by his chronometer. Thus, if he traveled *west* to Toronto, the *difference* between Toronto and Greenwich time, would be 5h. 17m. 26sec., which corresponds to 79° 21′ 30″, and is the longitude of Toronto west from Greenwich. The *differ-*

1. A *chronometer* is a time-keeper, constructed like a watch, made with great care and skill in order that it may measure time as perfectly as possible.

Wh*y* is the problem of longitude connected with astronomy? Define longitude? State the *f*o*ur* methods by which it can be determined? Explain what is meant by *local time?* Sho*w* how longitude can be determined by the chronometer? Give the example?

ences[1] between the *local times* of two or more places thus measure the differences of their longitudes.

712. If chronometers kept *perfect time*, no other method would be required to determine the longitude, but they are liable to errors in their rate of going, and though they have of late been greatly improved, yet they can not in general be relied upon for this purpose.[2]

713. BY ECLIPSES. The eclipses of Jupiter's satellites are phenomena, which are *visible at once* from all parts of the world where the planet is above the horizon. If therefore to-night an eclipse of a satellite should be noted at any two places on the globe, the *difference* in the *local times* of these places would give the *difference* of their *longitudes*.

714. But the laws that govern the motions of these bodies are well known, and the time of the occurrence of their eclipses at any station, as at Greenwich Observatory, can be calculated beforehand. Such calculations are accordingly made and published in tables.

When, therefore, an observer at New York, for instance, notes a certain eclipse of a satellite, he can ascertain the *longitude* of his station by taking his Greenwich tables, finding the time when this eclipse was predicted to occur at that observatory, and then comparing it with the *local time* of New York when the same event happened there.

715. The eclipses of the *sun* and *moon* are employed for the same purpose. This mode of obtaining the longitude does not admit of great accuracy, since it is im-

1. A difference in local time of *one hour* corresponds to 15° of *longitude*,
" " " of *one minute* " " 15′ " "
" " " of *one second* " " 15″ " "

2. Chronometers have however been constructed of surpassing accuracy. Thirty years ago an English artist of the name of French made two chronometers, which kept time with such exactness, that with one of them a navigator could have *sailed to China* and *back again* without making more than *half a mile of error* in his longitude. And with the other he could have *sailed around the world*, without having his greatest error in *longitude exceed fifty* or *sixty rods*.

Of what are the differences of local times the *measures*? Why can not chronometers in general be relied on for determining the *longitude*? Explain how longitude can be ascertained by means of eclipses? What other eclipses besides those of Jupiter's satellites are employed for this purpose?

possible to determine with perfect precision the exact moment when an eclipse *begins* and *ends*.[1] It is of no use to the mariner, for it can only be employed on land.

716. BY THE ELECTRIC TELEGRAPH. If two places are connected by *telegraphic lines*, the *difference* of their *longitudes* can be easily obtained by transmitting signals from one station to the other, and finding the *difference* in their *local times*. Thus, for example, if at the very moment a star is on the meridian of Philadelphia an observer there touches the telegraphic key and signalizes the fact to Washington, the *touching of the key* at the *former* city, and the *movement of the recording pen* at the *latter* occur *simultaneously*. Then, by comparing the *Philadelphia time* when these events happened with the *Washington time*, the *difference* in the *local times* of the two cities is obtained, and consequently the difference in their longitudes.[2]

717. In this manner, substantially, the respective differences of longitudes between Washington, Philadelphia, and Jersey City, were ascertained with great exactness in the summer of 1847.

In the following year, the difference of longitude between New York and Cambridge, and also that between Philadelphia and Cincinnati, were obtained by the same method.

718. This mode of determining longitude is not of universal application, but is regarded as one of the best wherever it can be employed, since it admits of great accuracy.

719. LUNAR METHOD. The *motions* of the *moon* are

1. In the determination of the longitude by means of an eclipse it must necessarily be observed by *different persons*, and with *different telescopes*. But telescopes *vary* in their power of revealing objects, and observers differ in the keenness of their vision. It thus happens that two persons, side by side, may assign different times to the *beginning* or *ending* of an eclipse.

2. Since the electric current occupies about *one second* of time in going through a *space of* 16,000 *miles*, allowance must be made for this *retardation* in *very long distances*. In short distances it may be safely neglected.

Why is not this mode of determining the longitude one of great exactness? Where can this mode only be used? Explain in what manner the longitude is obtained by the electric telegraph? In what instances has it thus been determined? What is said respecting the extent to which this mode can be employed? What in regard to the accuracy attainable by it?

now so well known, and her *course* through the heavens so precisely ascertained, that an astronomer can predict for every *tenth second* of time, for years to come, the *places* of the moon in the sky corresponding to these seconds. Her *exact position* being fixed, by ascertaining her distance from the sun, and from certain of the planets and several conspicuous stars that lie along her pathway in the heavens.

720. Tables of the moon's positions are computed with great care at well known observatories, in the reckoning of their respective *local times;* and by the aid of these, an observer, either on *sea or land*, determines the longitude of his station without difficulty.

721. The problem is thus solved. If a sailor, for instance, observes at 10 o'clock P. M., according to his *own time*, the position of the moon in respect to Jupiter, and finds upon turning to his Greenwich tables, that she is in the *same position* at Greenwich at 8 o'clock P. M.; he knows at once that he is in longitude 30° *east* of Greenwich; for the difference in the *local times* is *two hours*, and the Greenwich time is *behind* his own.

Describe the *lunar method*, and give the illustration?

PART THIRD.

THE STARRY HEAVENS.

CHAPTER I.

OF THE FIXED STARS IN GENERAL AND THE CONSTELLATIONS.

722. We pass now in imagination beyond the *solar system* and direct our attention to those *heavenly* bodies that lie beyond it.

723. The Fixed Stars. When we gaze at night upon the unclouded sky we behold, in addition to the objects already described, a multitude of sparkling *orbs*, varying in *brightness* and *magnitude*. These are termed the *fixed stars*, not because they are known to be actually *stationary* in space, for many of the stars are undoubtedly in *motion*, and possibly all may be; but from the fact that their *changes* in position, wherever noticed, are *so slow*, that compared with the swiftly moving members of the solar system, they may be regarded as *fixed*.

724. Magnitudes. Astronomers have classed the fixed stars according to their *degrees of brightness*. Those possessing the *greatest* splendor are termed stars of the *first magnitude*, while others which differ from the first by a *perceptible diminution* of brightness rank as stars of the *second magnitude*; and so on to the *seventh magnitude*, which is the *limit of visibility* to the *naked eye*. But the *telescope* now comes to our aid, and we discern stars ranging down in minuteness from the *seventh* to the *sixteenth magnitude*; and even beyond, the series ending, not from the want of stars to discover, but because our *noblest* instruments have not sufficient power to detect them.

725. It will be readily seen that this mode of classifi-

What does *Part Third* treat of? What is the subject of *Chapter I.*? To what do we now direct our attention? What is said of the *fixed stars*? How have they been classed by astronomers? How many magnitudes are visible to the naked eye? How far are these magnitudes extended by the telescope?

cation is *arbitrary* in its nature. The *diminution* in brightness, which distinguishes a star of one magnitude from that which immediately precedes it, can not be determined with mathematical precision, and is estimated by the eye alone. It therefore will vary with different persons, and it is impossible to tell where one magnitude ends and another begins; nevertheless, *usage* has determined among astronomers under *what magnitudes* are to be placed the numerous stars mapped down upon their *star-charts* and *celestal globes.*

726. It must also be borne in mind, that the *assumed magnitude* of a star determines nothing as to its *real size.* For the fixed stars are at different distances from us, and consequently a *star of moderate size* may, from its comparative proximity, shine with great splendor and be a conspicuous object in the heavens—while *another*, which far *surpasses* it in *intrinsic* brightness and magnitude, may yet be so remote as to rank many degrees of magnitude below the *former*, and perhaps be merged in obscurity amid crowds of orbs possessing equal splendor.

727. NUMBER OF STARS. The stars are literally *innumerable.* There are but 23 or 24 of the *first* magnitude, from 50 to 60 of the *second*, about 200 of the third; and as we descend in the scale the number comprised in the different classes rapidly increases. The number already noted down, from the *first* to the *seventh* magnitude inclusive, amounts to from 12 to 15,000, while the entire number registered amounts to 150,000 or 200,000.

728. But when the telescope sounds the depths of space, the heavens appear to be blazing with bright orbs, and the more powerful the instrument the more numerous are the stars revealed. Sir Wm. Herschel estimated, that, in a certain region of the sky remarkably rich with stars no less than 116,000 passed through the field of his telescope in the space of fifteen minutes, and

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Do the magnitudes mentioned include all the stars that exist? What is said respecting this classification? Does the assumed magnitude of any star determine any thing respecting its *actual size?* Why not? What is said respecting the number of the stars? How many are there of the *first* magnitude? Of the *second?* Of the *third?* What is said of their number as we descend in the scale? How many are noted down from the *first* to the *seventh* magnitude? What is the amount of the entire list registered? What is said of the number of stars observed when the *telescope* is employed? What estimate was made by Sir Wm. Herschel?

throughout the entire expanse of the heavens, it is reckoned that at least *one hundred millions of stars* are within the range of telescopic vision.

729. DISTANCE OF THE FIXED STARS. We have seen (Page 65, *note*) that the *parallax* of a heavenly body (as the moon) can be obtained, when it is viewed by different observers at the same time from different parts of the earth. And the *parallax* being known, the *distance of the body* from the earth can be computed without difficulty, (Art. 263.)

730. But when we attempt the same mode of observation on a fixed star, no *parallax* can be obtained; for so distant is the star, that the supposed lines drawn to it from the different places of observation make no appreciable angle with each other, but are *parallel.*

731. Astronomers, have therefore adopted *another method*, which consists in observing the position of a star in the heavens at some particular time, and repeating the observation *six months afterwards*, when the earth is in the *opposite* part of her orbit. The astronomer thus notes the situation of the star from *two stations* in space 190,000,000 miles asunder. But even this vast interval between the two points of observation produces so small a displacement of the star in the heavens, that observers were unable, until lately, to determine whether the star was *really unchanged in position or not.*

732. Accordingly if an inhabitant of one of the *nearest fixed stars* (if such inhabitants there are) were able to discern the earth, it would be difficult also for him to decide *whether it moved or not* in the heavens; for the *entire space comprised in its orbit* would at this immense distance occupy but a *mere point* of the sky.

733. In the beginning of the present century astronomers had advanced so far in their knowledge of the fixed stars, as to feel confident that no star visible in the northern latitudes could have a *greater parallax* than 1″,

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How many stars are believed to be within the range of telescopic vision? How is the distance of a heavenly body obtained? Can the parallax of a fixed star be found in the same way as that of the moon? What other method has been pursued by astronomers? Has it succeeded? Would the earth in passing from one part of its orbit to the *opposite, change* its *apparent place* in the heavens if observed from the nearest fixed star? What knowedge had astronomers of the parallax of the fixed stars at the beginning of the present century?

when viewed from *two points* in space *separated* by an interval equal to the *distance of the earth from the sun.* They had not succeeded in determining the *exact value* of the parallax of any star, yet they were sure that it could not *exceed* the quantity just mentioned. But since the above period the problem has been solved. The able astronomers of Europe, changing their method of investigation, at last directed their exquisitely constructed instruments towards a class of stars, termed *binary stars* (of which we shall soon speak,) and from numerous series of observations of the most refined nature have at length *determined the parallax of several fixed stars.*

734. PARALLAX AND DISTANCE OF ALPHA CENTAURI. In the years 1832 and 1833, Prof. Henderson, of Edinburg, made an extended series of observations, at the Cape of Good Hope, upon the star Alpha in the constellation of the Centaur, (α *Centauri*) one of the brightest stars of the southern hemisphere, from which he deduced a *parallax of* 1″. Other observations, made by Mr. Maclear in 1839 and 1840, with a much finer instrument, gave almost precisely the same result.

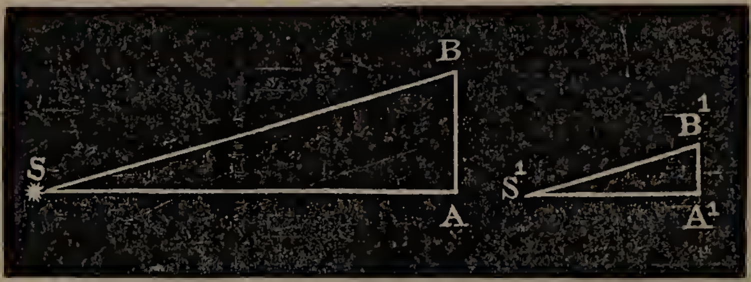
735. The parallax of Alpha Centauri, *exceeds* the known parallax of any other star, and, since the *greater* the parallax the *less* the *distance*, (Art. 95,) we may regard this star as the *nearest of all the fixed stars.* Since we know its *parallax*, we can compute its distance from the earth in *miles*, by proceeding in the manner we have frequently explained before.

736. In Fig. 84, let S represent the *star* α *Centauri*, AB the *radius of the earth's orbit*, SA and SB two imaginary lines drawn from the star, *one* to the *sun* at B, and the other to the *earth* at A; ASB an angle of 1″ and BAS a *right angle.* Now take $A^1B^1S^1$ a triangle *similar* to ABS, and supposing S^1A^1 to be *one mile in length* A^1B^1 will be *forty-eight thousand four hundred and eighty-one ten thousand millionths of a mile* (.0000048481 miles.)

Since this period has the parallax of any star been discovered? In what manner? Give an account of the researches of Prof. Henderson and Mr. Maclear? What is the *parallax* of Alpha Centauri? How does it compare in amount with that of other fixed stars? What inference is made from this fact? Having the parallax of a star, explain how its distance from the earth can be computed?

737. Calling AB 95,000,000 miles, we obtain from the *similar triangles* the following proportions; viz., A^1B^1 (.0000048481ths miles) : S^1A^1 (1 mile) : : AB

FIG 84.



DISTANCE OF A FIXED STAR.

(95,000,000 miles) : SA : multiplying the *second* and *third* terms together and dividing by the *first*, we obtain the value of SA, the *distance of the earth from the star*,[1] and find it to be nearly 19,600,000,000,000 miles, almost *twenty millions of millions of miles.*

737. The *velocity of light* is 192,000 miles per *second*, it would therefore take a ray of light about *three years and a quarter* to travel from the nearest *fixed star* to the earth.

738. Parallax and Distance of 61 Cygni. In 1838, Bessel, the renowned astronomer of Konigsberg, ascertained, beyond a doubt, the *parallax* of a double star in the constellation of the Swan, termed 61 Cygni. It was found to be about *one third of a second* (.348″) which proved that this star was distant from the earth, 592,000 *times* the earth's *distance from the sun.* It would take a ray of light more than *nine years* to pass from this star to our globe. Up to the present time the parallax of *nine* stars has been obtained, with more or less exactness.

739. Nature and Intrinsic splendor of the Fixed Stars. The *fixed stars* are supposed to be *suns*

1. The *distance* of the star *from the earth* may be regarded as equal to its *distance* from *the sun* for the reason mentioned in (Art. 732.) In the above figure therefore the *line* SB may be considered *equal* to SA.

What is the distance of the star Alpha Centauri from the earth in *miles?* How many *years* would it take for a ray of light to travel from this, the nearest fixed star, to the earth? When and by whom was the parallax of 61 Cygni discovered? How great is it? How far is this star from us? Of how many stars has the parallax been computed?

shining by their *own light.* Some of them greatly exceed our own in splendor. From computations based upon parallax, it has been estimated that Alpha Centauri possesses a brilliancy *two and one third times* (2.32) greater than that of our sun, while the dog-star Sirius, a magnificent orb, shines with the brightness of *sixty-three suns*

THE CONSTELLATIONS.

740. In *geography*, we observe that the entire surface of the globe is divided and subdivided into numerous *regions* and *districts* under different names. So likewise in the records of Astronomy we find, that from the earliest ages[1], the *visible heavens* have been divided into *spaces*, termed *constellations*, which are supposed to be occupied by the *figures of animals* and other objects; and whose *names* they respectively bear.

In some few instances the grouping of the stars that form a constellation, bears some resemblance to the figure which designates it, but for the most part we look in vain for any such correspondence.

741. Their Use. The constellations serve to indicate in a *general* manner *whereabout* a star is situated in the heavens, without fixing its *exact position.* Thus if a star is said to be in the *head of the Bull*, we know something respecting its situation, but there are *many stars* in the head of the Bull, and we can not tell what star is meant unless either its *right ascension* and *declination* are given, or its *celestial latitude* and *longitude.* These measurements determine its *precise situation* in the heavens and designate the star.

742. To illustrate from geography. If a traveler were to speak of an adventure that occurred in Egypt, we

1. In the book of Job, which, according to chronologists was written at least 3,300 years ago, the constellations of Orion and the Pleiades are particularly mentioned. The oldest Greek poets also speak of several of the constellations and principal stars. Thus Homer mentions Orion, the Bear, the Pleiades, and Hyades.

State what is said respecting the nature and intrinsic splendor of the stars? How have the visible heavens been divided from the earliest times? In what manner have these spaces been supposed to be occupied? What is said of the resemblance of the grouping of the stars in a constellation to the figure which represents it? What do the constellations serve to indicate? How is the *precise situation* of a star ascertained?

should know *whereabout* on the surface of the globe it happened, but not the *precise place*. This, however, we should ascertain at once if the *latitude* and *longitude* of the place were mentioned.

743. THE STARS IN THE CONSTELLATIONS.—HOW DESIGNATED. The stars of each constellation are distinguished from one another on *celestial globes* and *star-charts* by prefixing the *first* letter of the *Greek* alphabet to the *name* of any *constellation*, in order to designate the *brightest* star in that constellation. The *second* letter thus prefixed indicates the *second* brightest star, and so on through the entire alphabet. For example α Lyræ, or Alpha Lyræ is the *brightest* star in the constellation of the Lyre, β Orionis, or Beta Orionis, the *second* brightest star in the constellation of Orion, and γ Virginis, or Gamma Virginis, the *third* brightest star in the constellation of the Virgin.

744. When the stars that compose a constellation are more numerous, than the letters of the Greek alphabet, the *Roman* alphabet is employed when the Greek is exhausted; the letters being taken in their natural order, a, b, c, d, &c. But even these are insufficient, for the stars comprised within the largest constellations are reckoned by *hundreds* and *thousands*, and *figures* are therefore used when the stars of a constellation exceed in number the *letters* of the two alphabets.

745. PRINCIPAL CONSTELLATIONS. A list of the *chief* constellations is given below.

CONSTELLATIONS NORTH OF THE ZODIAC.

CASSIOPEA,	HERCULES,
ANDROMEDA,	THE SERPENT.
THE TRIANGLES,	OPHIUCHUS.
PERSEUS,	LYRA, THE HARP.
THE CAMELOPARD,	AQUILA, the Eagle.
AURIGA, the Charioteer,	ANTINOUS.
THE LYNX,	SOBIESKI'S SHIELD.
THE LESSER LION,	SAGITTA, the Arrow,

Illustrate from geography? Explain fully in what manner the stars in any constellation are distinguished from each other? Recite the names of the principal constellations *north* of the Zodiac?

URSA MAJOR, the Great Bear.
THE DRAGON,
BERENICE'S HAIR,
THE GREYHOUNDS,
BOOTES,
MOUNT MENALUS,
THE NORTHERN CROWN.
URSA MINOR, the Lesser Bear.
THE FOX AND GOOSE.
CYGNUS, the Swan.
DELPHINUS, the Dolphin.
THE LESSER HORSE.
PEGASUS, the Winged Horse.
THE LIZARD.
CEPHEUS.

CONSTELLATIONS OF THE ZODIAC.

ARIES, the Ram,
TAURUS, the Bull,
GEMINI, the Twins,
CANCER, the Crab,
LEO, the Lion,
VIRGO, the Virgin,
LIBRA, the Scales,
SCORPIO, the Scorpion,
SAGITTARIUS, the Archer,
CAPRICORNUS, the Goat,
AQUARIUS, the Water-bearer.
PISCES, the Fish.

CONSTELLATIONS SOUTH OF THE ZODIAC.

CETUS, the Whale,
ERIDANUS,
ORION,
THE HARE,
THE UNICORN,
THE GREAT DOG,
THE LESSER DOG,
ARGO NAVIS, the Ship.
THE HYDRA,
THE CUP,
CORVUS, the Crow,
THE SEXTANT,
CENTAURUS, the Centaur,
LUPUS, the Wolf,
THE SOUTHERN FISH.

746. These arbitrary divisions of the heavens are but of little practical use. "Astronomers," says Sir John Herschel, "treat the constellations lightly, or altogether disregard them, except for briefly naming remarkable stars. Nor is this disregard causeless, for they seem to have been almost purposely named and delineated to cause as much confusion as possible. Innumerable *snakes* twine through long areas of the heavens

Recite the names of the principal constellations *of* the Zodiac and of those *south* of the Zodiac? Are these arbitrary divisions of much use? What does Sir John Hersche' say respecting them?

where no memory can follow them, and *bears*, *lions*, and *fishes*, large and small, northern and southern, confuse all nomenclature."

747. HOW TO STUDY THE HEAVENS. In order to obtain a knowledge of the relative positions of the stars, the student of astronomy must gaze upon the heavens *for himself*. *Globes*, *books*, *and maps* are but of little use *alone*. They are merely intended to *aid* him, as he studies night after night the glowing fields of the firmament, which he can never fully explore.

748. Although the present work is designed simply to teach the *science* of *astronomy*, and not [1]*uranography*, or what has sometimes been called "the *geography of the heavens*," it may nevertheless be of advantage to the student to speak briefly of the *means* which he possesses to enable him to obtain a knowledge of the heavens, and also to show him how he is *to use* them.

749. THE CELESTIAL GLOBE. A *celestial globe* is a sphere, on the *outer surface* of which the *constellations* are delineated, and numerous stars and other objects in the visible heavens laid down with as much precision as possible.

It is, therefore, a *faithful copy of the celestial sphere*. *Ninety degrees* from each pole a strongly marked line encompasses the globe representing the *celestial equator*, and *inclined* to this, at the angle indicating the obliquity of the ecliptic (23° 27′ 43″.4) is another great circle, representing the *ecliptic*. *One* of the points were these two great circles intersect is the *first of Aries*. From this point the celestial *equator* is graduated into *degrees* and *parts of degrees*, indicating arcs of *right ascension;* and from the same point the *ecliptic* is graduated in like manner into arcs of *celestial longitude*. The ecliptic is, moreover, divided into the *twelve signs*, marked with their corresponding months and days.

750. The *globe* is surrounded by a *brass ring*, the *north* and *south* poles of the *former* being connected with the

[1] *Uranography*, derived from the Greek *ouranon*, heavens, and *graphë*, a description, i.e., a description of the heavens.

How are the heavens to be studied? Describe the celestial globe?

latter by means of *pivots;* so that the globe can easily revolve within the ring. The *brass ring* is accordingly a *celestial meridian*, and being graduated from the *equator* to *either pole*, from 0° to 90°, it measures arcs of *declination.* This *ring*, with the *globe* attached to it, is set *upright* in a *socket* in which it readily slides, so that any required elevation can be given to the *poles* of the *globe.* Enclosing the whole, and mounted upon a frame, is a *flat, broad ring* representing the *celestial horizon;* on the surface of which, for the sake of reference, the *signs of the zodiac* are drawn, and the *sun's place* in the *ecliptic* set down for *every day in the year.*

751. Around one of the poles of the globe a *small circle* is described having the *pole* for its *center*, the circumference being divided into 24 equal parts, marking the hours of the entire day. Attached to the pivot at the pole is a *brass needle*, which, as the globe revolves, remains stationary, and thus successively points to the hours of the day, as the numbers which indicate them pass in their turn beneath it. Other particulars might be mentioned respecting the *celestial* globe. but this description suffices for our present purpose.

752. HOW TO USE THE GLOBE. We will suppose it to be night; the student has his globe before him, and the stars shine clearly in the heavens. How shall he arrange his globe, so that the hemisphere that rises above its *artificial horizon* shall exactly represent the starry hemisphere that now glows above and around him? It is adjusted by the following rule. *Elevate the pole above the artificial horizon*[1] *to an altitude equal to the latitude of the place of observation. Then find the position of the sun in the ecliptic on the day of observation, and bring this point of the ecliptic directly beneath the brass meridian. Now turn the index to XII, and then cause the globe to revolve westward until the index points to the hour of observation.* The *constellations* figured on the globe are then situated, in respect to its *artificial* horizon, just as

1. In the regions of the earth *north* of the equator the *north pole of the celestial globe* must of course be elevated; and in those lying *south*, the *south pole.*

Explain how the celestial globe is to be adjusted and used?

the *real* constellations are, in regard to the *true celestial horizon.*[1]

753. The student thus prepared commences his study of the heavens, and by comparing his globe from night to night with the skies, he will at length become familiar with the position of the constellations, and of the principal stars that compose them.

754. STAR MAPS. On account of the expense of globes, various *celestial atlases* and *charts* have been made for those just beginning the study of the heavens, accompanied by explanatory text books.[2] In these only the most conspicuous stars are represented and described. For the advanced student and finished astronomer, *star maps* more full and elaborate are constructed with the utmost minuteness of detail; all the known stars being laid down in them with the greatest exactness.

755. By diligently comparing, under the guidance of their particular text books, these elementary charts with the heavens, the student soon obtains a general knowledge of the various *constellations*, and the respective situations of the most conspicuous *stars*.

CHAPTER II.

DIFFERENT KINDS OF STARS. STELLAR MOTIONS. BINARY SYSTEMS.

756. PERIODICAL STARS. Among the fixed stars

1. For example, it being required to find by the globe what stars are above the horizon at Hartford, Ct., on the 12th July, 1854, at 10 o'clock P.M., proceed by the rule as follows. *Elevate* the north pole of the globe 41° 45′ 59″ (the latitude of Hartford) above the *artificial* horizon. Then find from the globe the place of the sun in the ecliptic at *noon* on this day, and bring this *point* of the ecliptic directly under the *brass meridian.* Next turn the *index* of the hour circle to XII, on the *circumference* of the hour circle, and lastly revolve the globe *westward* until the hour index points to X. The *hemisphere* of the celestial globe above the artificial horizon will then faithfully represent the *visible heavens* at 10 o'clock, P.M., on the 12th of July 1854.

2. For instance Burritt's Geography of the Heavens. An excellent and cheap star chart, has been published by the Society for the Diffusion of Useful Knowledge.

State what is said of celestial charts and maps? What subjects are discussed in Chapter I.

several have been noticed which are subject to *periodical fluctuations* in *brightness*, and in one or two instances the star alternately *vanishes* and *reappears;* these are termed *periodical* or *variable* stars.

757. MIRA. The most remarkable orb of this class, and which has been observed for the longest time, is the star *Mira* (*o* Ceti) in the *constellation* of the *Whale.*

Its changing splendor was first noticed by Fabricius in 1596. It appears about *twelve times* in *eleven* years,[1] shining then for a space of *two weeks* with its greatest brilliancy, sometimes like a star of the *second magnitude.* It then *decreases* for about *three months*, till it becomes *invisible* to the *naked eye*, and so continues for the space of *five months more;* after which it *increases* in magnitude and brightness for the remainder of its period.

758. ALGOL. Another conspicuous periodical star is *Algol* in the *constellation* of *Perseus* (β Persei).

It generally shines as a star of the *second magnitude*, and continues so for 2d. 13h. 30m., when its splendor all *at once diminishes;* and in about $3\frac{1}{2}$ hours it appears only as a star of the *fourth magnitude.* Thus it remains for nearly *fifteen minutes*, when it begins to *increase*, and in $3\frac{1}{2}$ hours *regains* its *original brightness;* passing through all these variations in 2d. 20h. 49m. It is the opinion of astronomers, that these fluctuations may be caused by the *revolution* of some *dark body* around this singular star, which intercepts a large portion of the stellar light, when it is *between* the *star* and the *earth.* Between 30 and 40 *variable* stars have been detected by different observers, whose periods of changing brightness vary from a *few days* to *many years*, and the number discovered is annually increasing; so close a watch is kept upon the heavens by the sleepless eye of the astronomer.

759. TEMPORARY STARS. In different parts of the

1. Its period is 331d. 15h. 7m. By the term *period* is here understood in general the interval that elapses from the time of the star's greatest splendor to the time when it is next again brightest.

What are *periodical* or *variable* stars? Describe the variations of *Mira* and *Algol?* What is supposed to be the cause of the *variations* of Algol? How many *periodical* stars are now known? What is said as to the lengths of their respective *periods?* Is the list continually increasing? What are *temporary* stars?

heavens, stars have now and then been seen shining forth with great splendor, and after remaining for awhile apparently fixed, have gradually faded away, and to all appearance become *extinct.* These are called *temporary stars*, and differ from *variable* stars in this particular, that after once vanishing from our sight, they have *never been certainly known to reappear from time to time.* Perhaps when the science of astronomy is still farther advanced, it may be found that *temporary* stars, so called, are but in fact *variable* stars, of whose long periods of change we are yet ignorant.

760. *A temporary star* is said to have been observed by Hipparchus, of Alexandria, in the year 125 B.C., which suddenly flashed forth in the heavens with such splendor as to be visible in the day time.

In the year 389 A.D., a star of this class appeared in the *constellation* of the *Eagle.* For the space of *three* weeks it shone with the brilliancy of Venus, and then died entirely away. Temporary stars of great splendor were likewise seen in the years 945, 1264, and 1572 between the constellations of *Cepheus* and *Cassiopea.* From the circumstance that these stars appeared in the same region of the heavens, and also from the fact that the intervals of time between their epochs are almost *equal*, it has been supposed that they are *one and the same star*, which has a period of 312 years or possibly of 156.

761. The appearance of the star of 1572 was *very sudden.* The renowned Danish astronomer, Tycho Brahe, upon returning from his laboratory to his house, on the evening of the 11th of November 1572, found a number of persons gazing upon a star, which he was confident did not exist *half an hour before.* It was then as brilliant as *Sirius*, and continued to increase in splendor till it *exceeded Jupiter* in *brightness*, and was even *visible* at *noonday.* In December of the same year it began to *fade*, and by March, 1574, had completely disappeared. A *temporary star* of equal splendor blazed

What may they perhaps at length be found to be? Have *temporary* stars been noticed only in modern times? Describe the *temporary* stars observed in the years 389, 945, 1264, 1572, and 1670 A.D.?

forth on the 10th of October, 1604, in the constellation of Serpentarius, which *continued visible for a year.*

Another star of this kind, though less *brilliant*, was discovered in 1670 in the constellation of the *Swan.* It became *invisible*, and then *reappeared;* when after being subject to strange variations in its light for the space of *two years* it at length vanished, and has never been seen again.

762. The phenomenon of *temporary* stars has not yet ceased. Mr. J. R. Hind, who has distinguished himself by the discovery of so many planets, detected a temporary star on the night of the 28th of April, 1848, in the constellation of Ophiuchus. From his perfect acquaintance with this region of the heavens, Mr. Hind was sure that, up to the 5th of April, no star here existed below the *ninth magnitude.* The star in question was between the *fifth and sixth magnitude* at the time of its discovery, and shone with a ruddy hue. On the 2d of May of the same year it was of the *fifth magnitude*, and on the 24th of the *sixth.* By the 15th of August it had decreased to the *seventh magnitude*, and on the 23d of March, 1849, it ranked as a star of the *eighth magnitude.* In the month of June, 1850, according to Professor Loomis, it *could not be found.*

763. By comparing the heavens with existing *star-charts*, and the *ancient catalogues* of stars with the *modern*, it has been found that many stars are *missing.* "There is no doubt," says Sir John Herschel, "that these losses have arisen in the great majority of instances, from mistaken entries, and in some from planets having been mistaken for stars; yet in some it is equally certain, that there is no *mistake* in the *observation* or *entry*, and that the star has been *really observed* and *as really* has *disappeared* from the heavens." The class of *temporary* stars may therefore be much greater than is usually supposed, since, hitherto, it is only the most splendid that have attracted observation, and whose phenomena are recorded in the annals of science.

Has any star of this class been lately discovered? By whom and when? Relate the phenomena of this star? What is discovered by comparing the *heavens* with *celestial* maps, and the *ancient* catalogues of stars with the *modern.* What is remarked by Sir John Herschel on this point. Is there reason for believing that the number of temporary stars is greater than is generally imagined?

764. DOUBLE STARS. Many stars which appear *single* to the unaided eye, are found, when viewed through the telescope, to be in fact *two distinct stars* separated by a very small interval. Moreover, numerous *telescopic* stars, which are seen *single* when examined with ordinary instruments, are resolved into *two* when observed through telescopes of high magnifying powers. Stars of this kind are termed *double stars.*

765. CASTOR—ALPHA CENTAURI—61 CYGNI. The bright star *Castor* is one of the finest examples of a *double star*, it consists of two stars of between the *third* and *fourth* magnitude within 5″ of each other. *Alpha Centauri*, the nearest fixed star (Art. 735,) is also a remarkable *double star*, each of the component stars being at least of the *second magnitude*, and separated from each other by an interval of about 15″. The star 61 Cygni, whose distance from the earth was computed by Bessel, (Art. 738,) belongs also to this class; the individuals that compose it being of about the *seventh* magnitude, nearly equal in size, and about 15″ from each other.

766. COLORED DOUBLE STARS. Many double stars display a *beautiful variety of colors*, the component stars being of different hues.[1] Thus in the case of the double star Iota, in the constellation of the Crab, (ι Cancri,) the *brightest* of the component stars is *yellow* while the *other* is *blue.* The double star Gamma in the constellation of Andromeda (γ Andromedæ,) presents a different variation; the most brilliant component being *red* and its companion *green.* The star Eta in the constellation of Cassiopea, (η Cassiopeæ,) displays a combination of a *large white star* with a small one of a *rich ruddy purple.*

767. It is a singular fact that among double stars the *larger component* star is *never blue*, or *green*, while the smaller may be *blue*, *green*, or *purple.* *Single* stars of a

1. These colors are sometimes the mere effect of contrast, that is, are *complementary:* but they are not always so, for in numerous cases the component stars are *really* of different colors.

What are *double stars?* Give examples? What peculiarities in respect to the colors of the companion stars is observed? Is there only an *apparent* difference in color? Give instances of *colored double stars?* What has been noticed in regard to the *respective colors* of the *companion stars?*

deep red hue shine forth in various parts of the heavens, many of which are *variable.*

768. TRIPLE, AND QUADRUPLE OR MULTIPLE, STARS. When stars, which under common instruments appear *double*, are viewed through telescopes of greater power, a still further separation is not unfrequently effected. In some instances, *one* of the *twin stars* is resolved into *two*, and the combination is then termed a *triple star*. In other cases, *each* of the *two component* stars is separated into *two*; and since all the four appear but as a single star to the naked eye, it is called a *quadruple*, or *multiple star*.

769. EXAMPLES. The star Zeta in the constellation of the Crab, (ζ Cancri,) consists of three stars; two very close together, the *third* and *smallest* being most distant. The star Epsilon in the Lyre, (ε Lyræ,) is a remarkable *quadruple* star. With telescopes of low power it appears only *double*, but with the finest instruments *each component* is seen as a *double* star. The star Theta, in the constellation of Orion, (θ Orionis,) is likewise a conspicuous *multiple* star. It consists of four brilliant stars of the fourth, sixth, seventh, and eighth magnitude; and two of these, according to Sir John Herschel, are each closely attended by an exceedingly minute companion star. The arrangement of the several component stars in this combination, are shown in Fig. 85.

FIG. 85.

THE MULTIPLE STAR THETA IN ORION.

770. NUMBER OF DOUBLE AND MULTIPLE STARS.

What peculiar hue is displayed by many *single stars?* What are *triple* and *multiple stars?* Give instances?

Very few stars of this kind were known previous to the latter part of the last century. At this time Sir William Herschel arose, and with instruments at his command far superior to any before employed, and which his own genius and skill had constructed, entered this field of labor. An extraordinary success crowned his exertions. Though he knew but *four* double stars when he commenced his researches, he discovered within a few years more than 500, and during his life is said to have observed no less than 2,400 double stars.

771. The subsequent labors of his son, Sir John Herschel, of Sir James South, and of Prof. Struve, of Russia, have greatly increased this list. In 1833, when Sir John Herschel sailed for the Cape of Good Hope, in order to observe the celestial objects of the southern hemisphere, the whole number of known double stars was 3,346. While at the Cape this eminent astronomer discovered, in the space of about four years, no less than 2,196 stars of this kind. The number therefore of *double stars* at the present time is between *five* and *six thousand.*

STELLAR MOTIONS.

772. MOTION OF THE SOLAR SYSTEM. By comparing the positions of *three* conspicuous stars; viz., Sirius, Aldebaran, and Arcturus, as determined by *ancient* and *modern* observations, Dr. Halley discovered in 1717, A.D., (after making all due allowance for *precession, nutation,* &c.,) that they had *changed their places* in the heavens, since the time of Hipparchus, 140 years B.C. This motion is termed their *proper motion.*

The observations of succeeding astronomers have verified these conclusions, and a large number of stars are now known to have a proper motion.

773. In 1783, Sir William Herschel, by carefully

To whom are we chiefly indebted for our knowledge of double and multiple stars? Give an account of his labors, and state how large a number of these objects he discovered and observed? What distinguished astronomers subsequently pursued these researches? How great was the list of double stars in 1833? How many were added by Sir John Herschel while at the Cape of Good Hope? What is the entire number at present? What discovery was made by Dr. Halley upon comparing the places of certain stars as determined by *ancient* and *modern* observation? What is this motion called? Were these conclusions verified?

comparing the *proper motions* of those stars whose changes in situation were then best determined, came to the conclusion that the *sun with all its planets is actually moving from one quarter of the heavens towards the opposite region.* If the *solar system* is now really advancing through space, the stars belonging to that part of the sky toward which it is moving will necessarily appear to us gradually to *recede* from *each other;* while at the *same time* those which are situated in the opposite region of the heavens, and from which we are speeding away, will seem to *approach* each other and to *close together.*

Thus, if a traveler is passing through a forest, the trunks of the trees in the distance before him, and toward which he is moving, seem to *separate* farther and farther from each other, as he gradually approaches them; while those *behind* him *appear* by degrees to come *closer* together.

774. Phenomena like the preceding were detected by Sir William Herschel, in the *proper motion* of the stars. At a point in the constellation of Hercules, he found that there had been a *gradual separation of the stars,* and *toward* this region he believed the solar system was advancing.

775. The views of Herschel have been corroborated by the later and more extended observations of some of the most renowned living astronomers, and who have pushed their researches so far as to be able to estimate the speed of the solar motion. For, according to the computations of Struve, the *sun* with its train of *planets* and *comets,* is moving with a velocity of 422,000 miles *a day, toward* the same region in the constellation of Hercules which was pointed out by Sir William Herschel.

776. CENTRAL SUN. Does the sun move in a *straight line* or in *an orbit?* All celestial analogies indicate the latter, and Mädler of Dorpat Observatory, believes, from numerous observations which he has made, that he has

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What inference did Sir Wm. Herschel make from the proper motion of the stars? If the solar system is really advancing through space what stellar phenomena will occur, and why? Do these phenomena occur? To what point did Herschel believe the solar system was approaching? Have his views been established? State the results of modern researches? How fast does the *solar system* move according to Struve?

discovered the GREAT CENTRAL SUN, around which not only *our solar system* but the *stars themselves* revolve. *Alcyone* in the group of the Pleiades is supposed to be this central sun. Its *distance* from us is so great that it would require 537 *years* for a ray of light to pass from this orb to the earth, and, if our sun revolves about it, his *periodic time* must be no less than *eighteen millions of years.*

777. Without denying the possibility of this problem being eventually solved, astronomers at present consider the observations of Mädler to be insufficient to warrant his conclusions.

778. BINARY STARS. The *double stars* are divided into *two* classes. *First*, those which are *optically double*,[1] the two individuals appearing under ordinary circumstances as one object, simply, because they happen to be so near to one another that we view them in almost exactly the same line of direction. *No bond of union* exists between them; for one may be *millions of millions of miles behind* the other, and altogether beyond the reach of its influence. *Secondly*, double stars, which by their mutual attraction form *distinct sidereal systems;* the component stars *revolving about each other* in *regular orbits.* These, in order to distinguish them from double stars in general, are termed *binary stars*[2].

779. In 1803, Sir William Herschel, first announced the fact of the existence of binary stars; a discovery which was the fruit of 25 years assiduous and close observation. At the present time more than 100 *binary stars* have been discovered, and the list is continually increasing.

780. ORBITS—PERIODIC TIMES. The *orbits* of 15

1. Thus, in looking over a city, we not unfrequently see *two* steeples one behind the other, so nearly in the same line of direction that they appear as one object. At the first glance the figure formed by their union may seem *single;* a closer inspection shows that it is *optically double.*

2. *Binary*, from the Latin *binus*, meaning *two and two by couples.*

What are the views of Mädler respecting a *central sun*? What orb does he suppose it to be and where situated? How far is this orb from the earth? How long would the sun be in revolving around it? What views are entertained by astronomers respecting Mädler's theory? Into how many classes are double stars divided? Describe these classes? *When* and by *whom* was the existence of *binary* stars first announced? Of how many years research was this discovery the fruit? How many binary stars are at present known?

binary stars have been ascertained, and their *periodic times* with more or less certainty determined. Like the planets of our system they revolve in *elliptical paths*, and the correspondence that exists between their *calculated*, and *observed* positions in various points of their orbits, proves that the laws of gravitation extends to these far distant bodies.[1]

Their known *periodic times* range from 31 to 736 years. The names of a few of the binary stars, with their respective times of revolution are given in the following table,

NAME OF STAR.				PERIODIC TIME.
Zeta,	in the Constellation	of the Hercules,	(ζ Herculis,)	36 years,
Alpha,	" "	of the Centaur,	(α Centauri,)	77 "
Gamma,	" "	of the Virgin,	(γ Virginis,)	182 "
Castor,	" "	of the Twins,	(α Geminorum,)	253 "
Sigma,	" "	of the Crown,	(σ Coronæ,)	736 "

781. In contemplating the *systems of binary stars*, "we are not concerned," says Sir John Herschel, "with the revolutions of bodies of a planetary or cometary nature round a *solar center*; but with that of *sun around sun*—each perhaps accompanied with its train of planets and *their* satellites, closely shrouded from our view by the splendor of their respective suns."

CHAPTER III.

STARRY CLUSTERS--NEBULÆ--NEBULOUS STARS--ZODIACAL LIGHT--MAGELLAN CLOUDS--STRUCTURE OF THE HEAVENS.

782. Starry Clusters. When we turn our gaze upon the heavens in a serene night, we perceive that in some parts the stars are more *crowded together* than in others, forming by their close proximity *groups* or *clus-*

1. The *calculations* are made upon the supposition that these bodies revolve about each other in obedience to the laws of universal gravitation.

Of how many have the *orbits* and *periodic times* been ascertained with more or less accuracy? In what kind of orbits do they revolve? What fact shows that they are controlled in their motion by the *laws of universal gravitation*? What is said of the extent of their periodic times? Give the list? What does Sir John Herschel say respecting the systems of binary stars? Of what does Chapter III. treat?

ters. Such a cluster is the *Pleiades*, in which six or seven stars are seen by the naked eye, but where the telescope reveals *fifty* or *sixty* comprised within a very small space. The constellation, termed *Coma Berenices*, is another stellar cluster consisting of larger stars than those which form the group the Pleiades. In the constellation of the *Crab* is a *luminous spot*, called the *Beehive*, which a telescope of ordinary power shows to be constituted entirely of stars. In the *sword-handle of Perseus* is a similar spot, which, with a finer instrument, is revealed as *two clusters* of stars crowded thickly together.

783. "Many of the stellar clusters are of an *exactly round shape*," says Sir John Herschel, "and convey the complete idea of a globular space filled full of stars *insulated* in the heavens, and constituting in itself a family or society apart from the rest and subject to its own internal laws."

The *central portion* of a cluster is usually most thickly sown with stars, and the stellar light there shines forth with the greatest brilliancy. A beautiful cluster of this kind is found in the constellation of Hercules. It is represented in Fig. 86.

784. Number of Stars in a Cluster. The stars that compose a globular cluster are often exceedingly numerous. It has been estimated that not less than *five thousand* stars exist in some of the groups, *wedged together* into a space in the heavens, the area of which does not exceed one-tenth part of that covered by the moon.

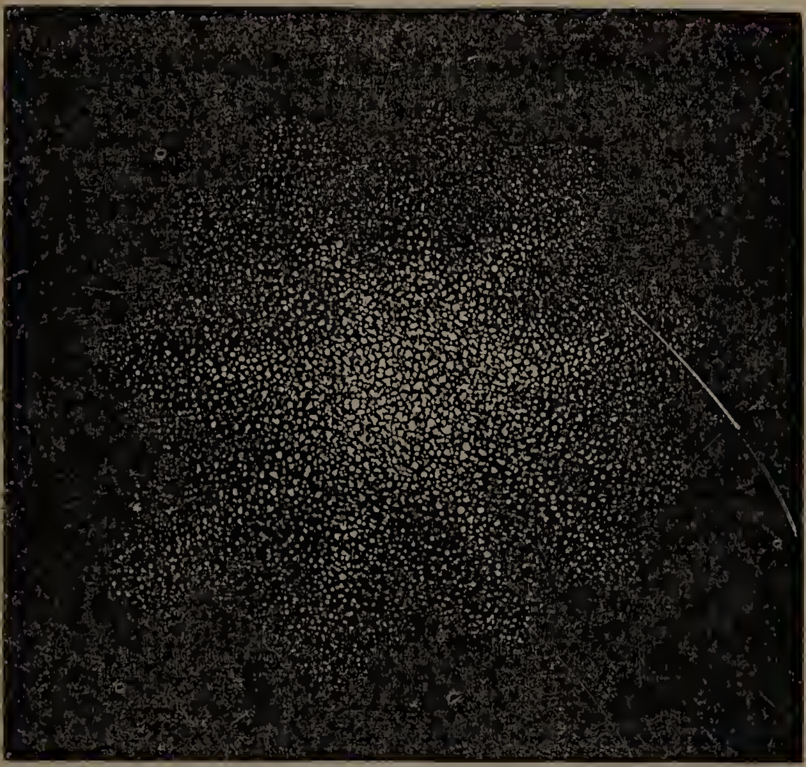
785. Milky Way, or Galaxy.[1] The most magnificent stellar cluster, by far, is the *milky way*, which like a broad zone of light encompasses the heavens. Its brightness is derived from the diffused radiance of *myriads* of *myriads* of stars that compose it, whose splendors are blended together into a *milky whiteness* on account of their immense distance from us.

786. In this cluster, Sir William Herschel estimated

1. From the Greek word *gala*, signifying *milk*.

Describe some of the stellar clusters? What does Sir John Herschel say in regard to stellar clusters? What is the usual appearance presented by the central portion of a cluster? What is said respecting the number of stars they contain? Which is the most splendid stellar cluster that the heavens present? What is its aspect, and whence is its light derived?

FIG. 86.



A GLOBULAR CLUSTER OF STARS IN HERCULES.

that, during *one hour's* observation with his telescope, no less than 50,000 stars passed before his sight within a zone 2° in breadth. Sir John Herschel has computed that the number of stars in the *milky way*, sufficiently visible to be counted, when viewed with his 20 feet telescope, amount in both hemispheres to *five and a half millions.* The *actual* number in this cluster he considers to be much greater, since in some parts they are so crowded together as to defy enumeration. Our sun is supposed to be one of the stars belonging to this group.

NEBULÆ.

787. Scattered throughout the sky are seen, either by the *naked eye* or by the aid of the telescope, *dim misty objects* of various shapes and sizes, *stationary to all appearance* like the stars themselves. These objects are named *nebulæ*[1], and are arranged under the following

1. For the meaning of this word, see page 13 note 3.

What observations and computations have been made which show that it contains a vast number of stars? What is supposed of our sun? What are nebulæ? How classified?

classes; viz., ELLIPTICAL, ANNULAR, PLANETARY, DOUBLE, SPIRAL, and IRREGULAR NEBULÆ.

788. ELLIPTICAL NEBULÆ. One of the finest specimens of this class is situated in the *girdle* of *Andromeda*. It is visible to the *naked eye*, and was noticed and described by Simon Marius in 1612; and there is reason for believing that it was seen even as early as 995. This nebulæ is of *vast size* extending over an area 15′ in diameter. It is delineated in Fig. 87.

FIG. 87

NEBULA OF ANDROMEDA.

789. ANNULAR NEBULÆ. A remarkable *annular* nebula easily detected with a telescope of ordinary power is found in the *constellation of the Lyre*. It has the appearance of a *flat oval ring*, the *central space* not being quite dark "but appearing," says Herschel, "to be filled with faint nebulæ, *like a gauze stretched over a hoop*." Nebulæ of this class are very rare. *Nine* comprise the entire number.

790. PLANETARY NEBULÆ. *Planetary nebulæ* are so called from their similarity in form *to planets*, being either *round* or somewhat *oval*. Only about 25 of this class

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Give examples of *elliptical* and *annular nebulæ*? How many of the latter kind are now known?

have yet been discovered, and nearly *three quarters* of this number are in the *southern hemisphere.*

One of the most beautiful is situated in the constellation of the Cross. It is a well defined circular figure, 12″ in diameter, looking exactly like a planet. It has the brightness of a star of between the sixth and seventh magnitude, and shines with a rich *blue* light inclining to *green.* A magnificent planetary nebula is found in the *constellation* of the *Great Bear.* Its apparent diameter is 2′.40″, and upon the supposition that it is at the *same distance* from the earth as the double star, 61 in the Swan, the actual diameter of this nebula is *seven times greater* than the *diameter* of Neptune's orbit; that is, more than *forty thousand millions of miles.*

791. DOUBLE NEBULÆ. A few only of these objects have been detected. The individuals that form them belong to the class of *planetary nebulæ.* All the varieties of *double stars,*" says Herschel, "in respect to *distance, position,* and *relative brightness* have their *counterparts* in *double nebulæ.*"

792. SPIRAL NEBULÆ. The discovery of a number of nebulæ presenting the appearance of *spirals* or *whirlpools,* has lately rewarded the researches of astronomers. They are a singular class of stellar objects altogether different from any before known, requiring the very finest telescopes to reveal their structure. For though the telescopes of the Herschels and other able astronomers had been sweeping over them for the space of nearly a hundred years, their true nature was only disclosed beneath the powerful telescopes of Lord Rosse[1].

793. IRREGULAR NEBULÆ. *Irregular nebulæ,* as their name implies, are entirely destitute of any regularity in form. They are of very *great extent* and are found either *within* the *milky way* or *skirting* its edges.

1. The Earl of Rosse has constructed a reflecting telescope, the mirror of which is *six feet in diameter* and weighs *three tons.* The tube of the telescope is *fifty-six feet* in length. This instrument is the *greatest*, and the most *powerful* of any that has ever been constructed.

Give instances of *planetary nebulæ?* What is said respecting *double nebulæ* and *spiral nebulæ?* What are *irregular nebulæ?*

The most splendid of this class is the nebula in the *sword-handle of Orion.* It consists of straggling *cloudlike spots*, occupying a space in the heavens considerably larger than the *disk of the moon.* This nebula was discovered by Huyghens in 1656. In Fig. 88, its central por-

FIG. 88.

NEBULA OF ORION.

tions are shown as they have been delineated by Sir John Herschel.

794. THEIR CONSTITUTION. *Stellar clusters* and *nebulæ* have usually been regarded as *distinct classes* of celestial objects; the *former* consisting of groups of stars, either visible to the naked eye or through the telescope, and the *latter* of vast collections of unformed matter diffused

Which is one of the most splendid? What views have been entertained respecting stellar clusters and nebulæ?

through the infinitude of space. But it is by no means certain that such a distinction exists in nature, for the late discoveries of eminent astronomers point to the conclusion, that the *nebulæ are clusters of stars more or less distant from us. The nearest* and *least* crowded requiring but ordinary telescopes to resolve them into stars; while those which are *farther off*, and *more thickly* studded with stars, can be resolved only by instruments of greater excellence and power.

795. Sir William Herschel divided nebulæ into *two great classes;* viz., those which *could* be separated into stars by the telescope, and those that *could not;* the *former* were termed *resolvable* nebulæ, and the *latter irresolvable.*

796. But since the time of this renowned astronomer the telescope has been wonderfully improved, and discoveries made corresponding with its higher degree of perfection. Nebulæ, which had before been regarded as *irresolvable*, have successively yielded to the increased power of the telescope, and been revealed as *splendid clusters* of stars.

797. For a long time the nebula in Orion withstood the highest powers of the telescope to resolve it, but when, during the winter of 1845, it was examined by Lord Rosse, in his immense telescope, it was seen brilliant with vast collections of stars, proving that it was really a *stellar cluster.*

The great nebula in Andromeda, when viewed through the noble instrument belonging to Harvard University, appears to be *studded over* with *multitudes of stars*, which form however no portion of the nebula. This object at present is regarded as *unresolved.*

798. But while the augmented power of the telescope has resolved numerous *known nebulæ* into *starry groups*, increasing the number of the one at the expense of the other; it has also brought to light from the depths of space many nebulæ which *were before invisible;* for even in the powerful instrument of Lord Rosse *misty objects*

To what conclusion do the late discoveries of astronomers point? Into what two great classes did Sir William Herschel divide the nebulæ? What advances in this field of research have been made since his time? What has the nebula of Orion proved to be? Has that of Andromeda been resolved?

before unseen, are revealed as *nebulæ*, without any signs of resolvability. What are these new objects? Are they mere collections of matter, or clusters of stars?

799. Upon this point Sir John Herschel thus remarks, "it may reasonably be doubted whether the distinction between such nebulæ as are *easily* resolved, *barely* resolvable with excellent telescopes, and *altogether* irresolvable with the best, is any thing else than *one of degree;* arising merely from the *excessive minuteness*, and *multitude* of the *stars* of which the *latter*, as compared with the *former*, consist."

800. NUMBER AND DISTANCE OF STELLAR CLUSTERS AND NEBULÆ. About *two thousand* stellar clusters and *nebulæ* were observed by Sir William Herschel. In 1833 the list amounted to *two thousand five hundred*, and this number was increased to about *four thousand* by the splendid discoveries made by Sir John Herschel, during his residence at the Cape of Good Hope. The distance of the *nebulæ* from the earth is vast beyond conception. The *ring nebula* in the Lyre is so remote, that astronomers assert a ray of light cannot reach us from this object in less than *twenty* or *thirty thousand years*.

The nebula of Orion is still more distant, for it is computed that a ray of light, moving as it does with a velocity of 192000 miles in a second, would occupy not less than *sixty thousand years* in travelling from this nebula the earth.

801. THEIR PHYSICAL STRUCTURE. Mathematicians have clearly shown it to be utterly impossible that the stars composing individual clusters and nebulæ could have been so grouped together by *mere chance.*[1] Their union must consequently be the result of some *physical*

1. Mitchell has shown that if 1500 stars, like the six brightest in the Pleiades, were scattered *at random* through the heavens, there would be only *one chance* out of *five hundred thousand* that *any* six of them would come as close together as they do in the Pleiades.

What other discovery besides the separation of many nebulæ into starry clusters, has resulted from the increased power of the telescope? Are these telescopic nebulæ also stellar groups? State Sir John Herschel's opinion? Relate in full what is said respecting the number and distance of *stellar clusters* and *nebulæ?* State what is said of our distance from the nebula of Orion? What is remarked in regard to the physical structure of stellar clusters and nebulæ?

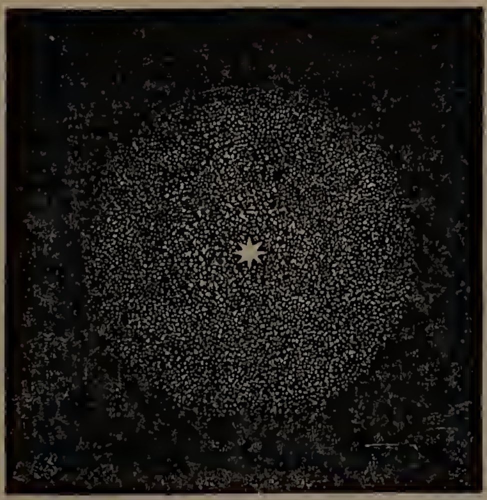
law impressed upon them by their Creator, in virtue of which they are combined in harmonious systems. This view is strengthened, when we perceive that these clusters tend to assume in numerous instances *distinct forms;* many of them appearing *round* like a planet, with their outlines sharply defined; the component stars *toward the center* being often *closer together* than at the *borders.*

802. We have therefore reason for believing that a *stellar cluster* is a *celestial system composed of solar systems*, each individual star being a *sun*, having its attendant train of planets and comets like our own. Every sun being separated from its *brother suns* by enormous intervals of space, although, owing to the vast distance at which we view them, they appear to us *crowded* and *wedged together.*

803. Under the action of *universal gravitation* matter assumes a spherical shape and is the *densest* at the *center.* The *globular* form of some of the stellar clusters, and the closer union of the stars toward the *central* parts, point to this influence as that which unites and controls these *starry systems*, or *island universes*, as they have been aptly termed.

804. NEBULOUS STARS. In various parts of the heavens bright and sharply defined stars are beheld enveloped in a *cloudlike disk* or *atmosphere*,—these are called

FIG. 89.



A NEBULOUS STAR.

Must their union be the result of some physical law? What facts strengthen this view? What have we reason for believing? What is the influence which probably unites and controls these starry systems? What are *nebulous stars?*

nebulous stars. In some cases this *hazy* envelope is *circular* in form, with the star situated in the center, in others it is *elliptical;* and there are instances where the nebulous atmosphere has no definite boundary, but fades away by degrees in every direction. The appearance presented by a nebulous star is shown in Figure 89.

805. ZODIACAL LIGHT. The *zodiacal light* is a luminous object *shaped like a pyramid*, that accompanies the sun in his apparent course through the heavens.

806. ASPECTS. According to Prof. Olmsted, who has made this phenomenon an especial study, the *zodiacal light*, in our climate, becomes visible in the eastern sky about the *beginning of October.* It is then seen before the dawn, its *base* resting upon that part of the horizon where the sun at this time rises, the luminous pyramid extending, obliquely upward, until its point reaches above the starry cluster of the Beehive, in the constellation of Cancer. Throughout the *month of December* it is beheld on *both sides* of the sun, being seen in the *morning before sunrise*, and in the *evening* after *sunset*, extending in the *first case* sometimes as far as 50° *westward* from *the sun*, and in the *second* 70° *eastward.* In February and March the zodiacal light appears only in the *west after sunset;* it is then most conspicuous, and its luminous point is seen as far up as the Pleiades.

807. SIZE. This object possesses no well defined outline, but its light gradually fades away from the central to the outer portion, until it becomes too faint to be discerned. Its *breadth* at the base varies from 8° to 30° according to Herschel, but Prof. Olmsted has noticed it when it was 40° in *width.*

From the observations of the latter gentleman it appears, that the *zodiacal light* sometimes extends *in length* considerably beyond the orbit of the *earth;* for on the 18th of December, 1837, it was beheld stretching away *eastward* from the *sun* to the distance of 120°.

807. NATURE. Sii John Herschel conjectures that the zodiacal light is an elongated *oval shaped envelope*, en-

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State their various aspects? What is the *zodiacal light*? What are its aspects in oui climate? What is stated respecting the size of the zodiacal light?

closing the sun, consisting of extremely light matter, and possibly composed to a great extent of the same materials which form the *tails of* comets. Under this view, the sun *surrounded* by the *zodiacal light* presents a phenomenon similar to that of the *nebulous* stars.

809. Professor Olmsted, whose opinions on this subject are entitled to great weight, believes that the zodiacal light is a *nebulous* body which *revolves* about the sun, and is probably the cause of the splendid meteoric showers that occur from time to time.

810. MAGELLAN CLOUDS. This name has been given to two *vast luminous* objects, clearly visible to the naked eye in the southern hemisphere, and similar in appearance to the *Milky Way*. They differ in *size*, the *smallest* being the *brightest*, but *both* of them possess an *oval form*.

811. These *cloudlike tracts*, when examined through telescopes of great power, are found to be composed of *separate stars*, *stellar groups* and *nebulæ*. Among the stellar groups are *globular* clusters with their component stars more or less crowded together, while the *nebulæ* exhibit in profusion every variety found in other parts of the heavens, and in addition some which are peculiar to this region.

812. *Within* the *larger* of the *Magellan clouds* no less than 278 *clusters* and *nebulæ* have been discovered, while on the *outskirts* from 50 to 60 more are seen. The *smaller* contains 37 of these objects and 6 others are found upon its *borders*.

813. STRUCTURE OF THE HEAVENS. Different systems have from age to age been presented to the world, professing to explain the *structure of the heavens*. The *three* which especially deserve notice are the *Ptolemaic*, the *Tychonic*, and the *Copernican*.

814. PTOLEMAIC. According to this system the earth is *immoveably* fixed in the *center of the universe*, while all the heavenly bodies revolve about it from *east* to *west*. It was established by Ptolemy, an Egypt-

What are the views of Sir John Herschel in regard to its nature? What are those of Professor Olmsted? Describe the Magellan clouds? Give an account of the principal different systems which have professed to explain the *Structure* of the *Heavens*?

ian astronomer in the second century of the Christian era, and prevailed for more than 1500 years.

815. TYCHONIC. This system originated with Tycho Brahe, who flourished in the sixteenth century. Like Ptolemy he believed that the earth was *stationary* in the *center* of the universe, and that the stars, and the sun and moon, revolved around it; but he conceived that the *planets* revolved *directly about the sun.*

816. COPERNICAN. So called from Nicholas Copernicus, an illustrious astronomer of the fifteenth century. According to the Copernican system, the earth *rotates on her* axis from *west* to *east*, and *revolves* with the rest of the planets around this sun, in the same direction. This system is the *true* one, for it is not only *mathematically* demonstrated to be *correct*, but it *perfectly* explains *all celestial phenomena*, which every other system fails to do.

817. The *structure of the heavens* was briefly explained in the beginning of this work, (Arts. 4, 5,) in accordance with the Copernican system, and as we have advanced in our investigations, it has been gradually unfolding in part to our view.

Commencing with the earth, we have found that it both *rotates* on its *axis* and *revolves* about the *sun*, while around it circles a shining moon. It has been further shown that the earth is not *isolated*, but is one of a *brotherhood* of planets, endowed with the *same motions*, and in several cases similarly attended. All these with *myriads* of comets constitute the *solar system.*

818. Exploring further, we behold in the *binary stars*, *suns revolving about each other* with their respective trains of *planets* and *comets*, exhibiting the phenomenon of SOLAR SYSTEMS IN MOTION.

Piercing deeper into abysses of space *stellar clusters* and *nebulæ* stand forth revealed: objects of surpassing grandeur and magnificence. For here *suns crowd* upon *suns*, forming a vast and numerous GROUP OF SOLAR SYSTEMS—united to all appearance by a *common* bond. Possibly these associated systems *revolve about* some mighty sun centrally situated within the radiant

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Which is the true system, and why? Explain the *Structure* of the *Heavens* in accordance with the Copernican system?

group; for if our *solar system*, together with *the stars* that glitter in our firmament, is really revolving around some *central sun*, analogy would lead us to infer, that similar motions also exist amid these starry clusters and nebulæ.

819. When the scroll of the skies is still farther unrolled for our perusal, we may perhaps find that these *island universes* themselves move in *orbits* around some common center.

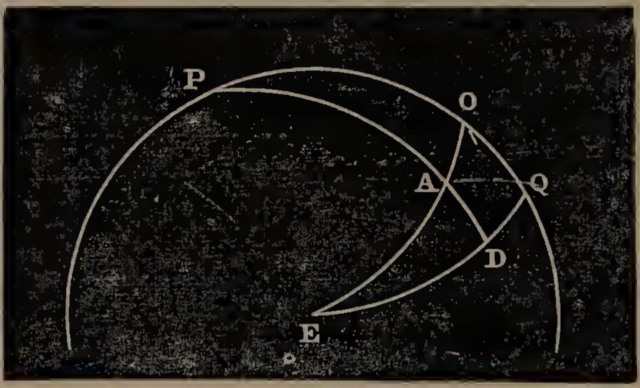
For with all our surprising discoveries we are yet upon the very *threshhold* of creation; and could we continue to explore beyond the remotest nebulæ, through the successive realms of space, new scenes of grandeur would perpetually unfold; and new fields of Omniscient display would be constantly revealing, that God was still before us in his creative energy, and that we saw but the "HIDINGS OF HIS POWER."

Although not in strict accordance with the plan of this work, it has been thought that a few astronomical problems might not be unacceptable to those students who possess a knowledge of Plane and Spherical Trigonometry. On this account the following problems have been prepared.

ASTRONOMICAL PROBLEMS.

Of four quantities, viz.: the sun's *longitude, declination, right ascension*, and the *obliquity of the ecliptic*, any *two* being given to find the rest.

(1)



In figure 1, let EC represent the ecliptic, EO the equator, and P the pole of the equator. Let A be the place of the sun, and PAD the arc of a great circle passing through the pole and the sun. Then EAD is a *right-angled spherical triangle*, right-angled at D, and AD is the sun's *declination*, AE its *longitude*, ED its *right ascension*, and AED the *obliquity of the ecliptic.* Any two of these quantities being given the rest can be found by Napier's rule.

I. Given, the sun's longitude and the obliquity. Required, the *right ascension* and *declination.*

Problem 1. If the sun's longitude is 30° 27′ 42″, and the obliquity of the ecliptic 23° 27′ 42″; what is the *right ascension* and *declination?*

By Napier's rule, R×Sin. AD=Sin. AE×Sin. AED.

R,	10.
Sin. 30° 27′ 42″,	9.704975
Sin. 23° 27′ 42″,	9.600031
Sin. AD, declination (11° 38′ 40″),	9.305006

Ans. { Declination, 11° 38′ 40″.
Right Ascension, 28° 20′ 52″.

PROB. 2. If the sun's longitude is 40° 45′, and the obliquity of the ecliptic 23° 27′ 20″; what is its *right ascension* and *declination?*

Ans. { Declination, 15° 03′ 34½″.
Right Ascension, 38° 19′ 29″.

II. Given, the obliquity of the ecliptic and the sun's right ascension. Required, the *declination* and *longitude.*

PROB 1. The obliquity of the ecliptic being 23° 27′ 29″, and the sun's right ascension 69° 30′; what is its *declination* and *longitude?*

By Napier, R×Sin. ED=Tang. AD×Cot. AED

Cot. 23° 27′ 29″,	10.362568
R.,	10.
Sin. 69° 30′,	9.971588
Tang. AD (22° 7′ 12″),	9.609020

Ans. { Declination, 22° 7′ 12″.
Longitude, 71° 4′ 08″.

PROB. 2. If the obliquity of the ecliptic is 23° 27′ 25″, and the right ascension of the sun 55° 20′ 20″; what is its *declination* and *longitude?*

Ans. { Declination, 19° 38′ 32″.
Longitude, 57° 36′ 51″.

III. Given, the obliquity of the ecliptic, and the sun's declination. Required, the *longitude* and *right ascension.*

PROB. 1. The obliquity of the ecliptic, on the 31st of May, 1855, was 23° 27′ 36″ and the declination of the sun 21° 52′ 56″; what was its *longitude* and *right ascension?*

By Napier's rule, R×Sin. AD=Sin. AE×Sin. AED.

Sin. 23° 27′ 36″,	9.600002
R.,	10.
Sin. 21° 52′ 56″,	9.571360
Sin. AE (69° 25′ 9″),	9.971358

Ans. { Longitude, 69° 25′ 9″.
Right Ascension, 67° 44′ 20″.

PROB. 2. The obliquity of the ecliptic, on the 8th of September, 1857, being 23° 27′ 38″, and the declination of the sun 5° 58′ 8″; what is its *longitude* and *right ascension?*

Ans. { Longitude, 15° 8′ 30″.
Right Ascension, 13° 56′ 27″.

IV. Given, the sun's right ascension and declination. Required, the *longitude* and the *obliquity* of the ecliptic.

PROB. 1. The right ascension of the sun being 41° 3′ 54″, and its declination 15° 54′ 45″; what is its *longitude*, and the *obliquity* of the ecliptic?

To find the obliquity. By Napier, R×Sin. ED=Tang. AD ×Cot. AED.

Tang. 15° 54′ 45″,	9.454988
R.,	10.
Sin. 41° 03′ 54″,	9.817510
Cot. AED (23° 27′ 37″),	10.362522

Ans. { Obliquity, 23° 27′ 37″.
Longitude, 43° 31′ 30″.

The learner will recollect that from the vernal equinox to the summer solstice the declination is *north* and *increasing;* from the summer solstice to the autumnal equinox, *north* and *decreasing;* from the autumnal equinox to the winter solstice, *south* and *increasing;* and from the winter solstice to the vernal equinox, *south*, and *decreasing;* moreover, that longitude and right ascension, are reckoned from the vernal equinox, completely round, that is, 360°. The preceding examples are comprised in the first quadrant, from the vernal equinox to the summer solstice. For examples in the second

quadrant, E would be regarded as the autumnal equinox, and ED and EA would have to be subtracted each from 180°, and the remainders would be, respectively, the corresponding right ascension and longitude.

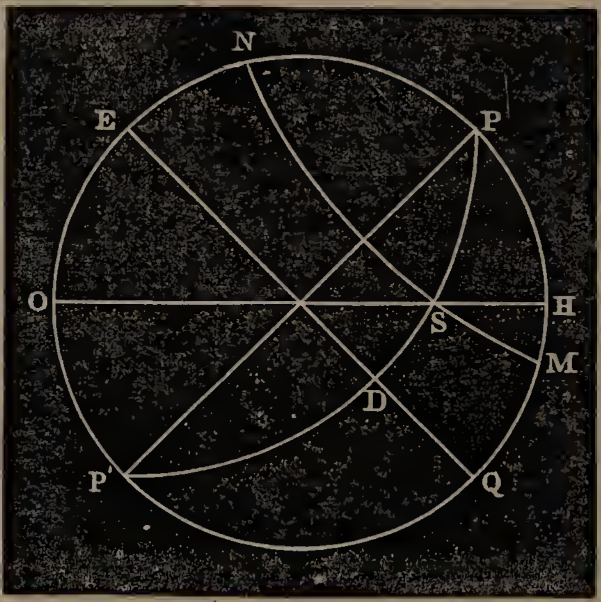
In the third quadrant, viz.: from the autumnal equinox to the winter solstice, E would be regarded as the autumnal equinox, and ED and EA, being added, respectively, to 180°, the sums would be the right ascension and declination. In examples in the fourth quadrant, viz.: from the winter solstice to the autumnal equinox, E would be the vernal equinox, and the right ascension and longitude would be found by subtracting ED and EA from 360°. These facts will be evident by the inspection of figure 20.

PROB. The sun's *right ascension* being 243° 44′ 36″, and its *declination* 21° 16′ 4″; what is its longitude?

The right ascension being more than 180°, shows that the problem is in the third quadrant, and 243° 44′ 36″—180= 63° 44′ 36″=ED. The value of EA, as found by Napier's rule, is 65° 39′ 10″, which, added to 180°,=245° 39′ 10″, which is the answer.

Given, the latitude of the place of observation, and the sun's declination, to find the time of its rising and setting.

(2)



In figure 2, let the circle NPMOE be the meridian of the place, HO the horizon, and EQ the equator. P is the elevated pole of the heavens, and S the place of the sun when on the horizon. MSN the apparent path the sun describes between midnight and noon, for it is evident that when the sun is at N it is noon, and when at M, on the meridian below, it is midnight. DS is the sun's declination. Now in the right-angled spherical triangle PSH, right-angled at H, there are given the *latitude*, PH, (Art. 57,) and PS, the *co-declination*, to find the hour angle SPH, which, reduced to time, shows how long the sun takes to pass in its apparent course, M to S.

Then by Napier's rule, R$\times$Cos. SPH=Tang. PH$\times$Cot. PS or Tang. DS.

PROB. 1. At what time does *sunrise* occur at Fort Leavenworth, N. Lat. 39° 21′ 14″, when the sun's declination is 15° 50 North?

R.,	10.000000
Tang. 15° 50′,	9.452706
Tang. 39° 21′ 14″,	9.913847
Cos. SPH, 76° 33′ 06″,	9.366553

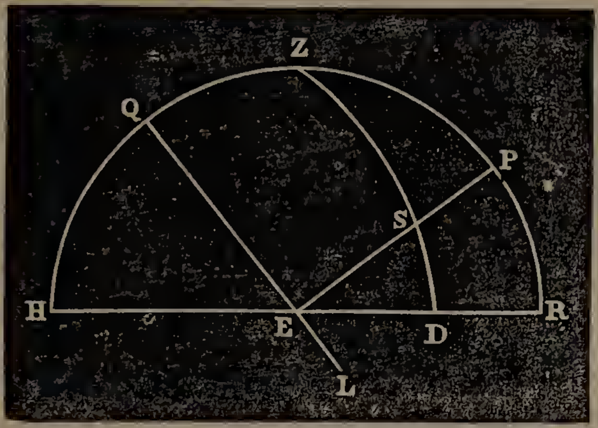
Dividing 76° 33′ 06″ by 15, (Art. 91,) to obtain the time, we have 5h. 6m. 12s. for the time of sunrise. Subtracting this time from 12 hours gives 6h. 53m. 47.6s. for the time from sunrise to noon, and also the time of sunset.

PROB. 2. What is the *length of the day* at Yorktown, Va., N. Lat. 37° 13′, when the declination of the sun is 19° 20′ 10″?

Ans., 14h. 3m. 39.2s.

To find the altitude and azimuth of a star when it is six hours from the meridian, its declination, and the latitude of the place of observation being known.

(3)



In figure 3, let S be the star, P the pole of the heavens, Z the zenith of the place, and QL the equator—RZH is a meridian, PSE an hour circle, and ZSD a vertical circle. As the star is six hours from the meridian, ZPS is a *right angle*, and the circle PSE cuts the horizon in the *east* and *west* points; PER is the *latitude* of the place, and ES is the *declination* of the star.

Then by Napier's rule we have in the right-angled spherical triangle, SED, R×Sin. SD (altitude)=Sin. SED× Sin. SE; and R×Cos. SED=Cot. SE×Tang. ED (amplitude) .90°—amplitude=azimuth.

PROB. 1. Find the *altitude* and *azimuth* of the star Castar, at Toronto, N. Lat. 43° 39 35″, when it is six hours from the meridian, its declination being 32° 12′ 10″.

Cot. 32° 12 10″,	10.200796
R.,	10.
Cos. 43° 39 35″,	9.859410
Cot. of azimuth or Tang ED, amplitude (65° 30′ 16″),	9.658614

Ans. { Azimuth, 65° 30′ 16″.
Altitude, 21° 35′ 13″.

PROB. 2. At Knoxville, Tenn., N. Lat. 35° 59′, the declination of the sun being 20° 20′, what is its *azimuth* and *altitude* at 6 o'clock in the evening?

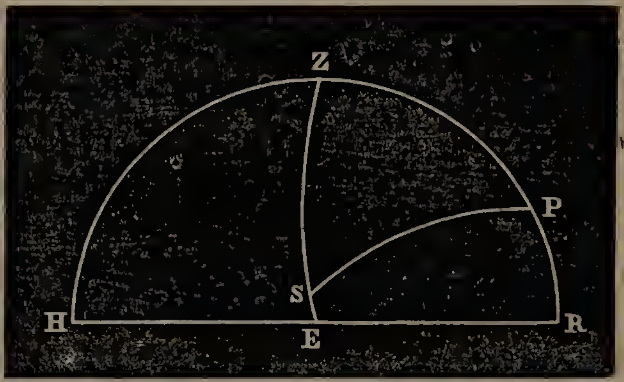
Ans. { Azimuth, 73° 18′ 29″.
Altitude, 11° 46′ 50″.

PROB. 3. In N. Lat. 42° 50′, the altitude of the sun, at 6 o'clock in the morning, was found to be 15° 25′, what was its *azimuth* and *declination?*

Ans. { Azimuth, 72° 41′ 45″.
Declination, 23° 01′ 03″.

If a star is on the prime vertical, its altitude and hour angle may be obtained, when its declination, and the latitude of the place is known.

(4)



In figure 4, let S be the star, P the pole of the heavens, HZPR a meridian, PS an hour circle, ZSE the prime verti-

cal, and HER the horizon. Then, in the spherical triangle ZPS, the angle SZP is a right angle. PS is the *co-declination*, and PZ the *co-latitude*, both known quantities.

We have, therefore, by Napier's rule, R×Cos. ZPS (hour angle)=Cot. SP×Tang ZP; and R×Cos. SP=Cos. ZS× Cos. PZ. ZS=co-altitude.

PROB. 1. Find the *altitude* and *hour angle* of Arcturus, when exactly west of an observer at Montreal; the declination of the star being 19° 56′ 10″ North, and the latitude of the place 45° 31′ North.

For the altitude.

Sin. 43° 31′,	9.853366
R.,	10.
Sin. 19° 56′ 10″,	9.532719
Sin. of altitude or Cos. of co-altitude (28° 32′ 58″),	9.679353

Ans. { Altitude, 28° 32′ 58″.
Hour angle, 69° 7′ 53″.

PROB. 2. Find the *altitude* and *hour angle* of Markab, when east of an observer at Alexandria, Va., the declination of the star being 14° 25′ 50″, and the latitude of the place 38° 49′.

Ans. { Hour angle, 71° 20′ 45″.
Altitude, 23° 25′ 34″.

Application of Kepler's third law, that the squares of the periodic times are as the cubes of the distances.

In calculations founded upon this rule it is convenient to take for two terms of the proportion the *periodic time* of the earth, and its *mean solar distance*, calling the latter *unity;* and expressing the solar distances of other planets in multiples and fractions of this.

The length of the siderial year in mean solar days is 365.256374417.

The logarithm of 365.256374417 is 2.5625978.

Given, the earth's periodic time and solar distance, and also the solar distance of a planet, to find the *periodic time* or siderial revolution of the latter.

PROB. 1 If the mean solar distance of Ceres is 2.765765, (calling the earth's solar distance 1,) what is her periodic time?

$1^3 : \overline{365.256374417}^2 :: \overline{2.765765}^3 :$ the square of the periodic time of Ceres.

By Logarithms,

1^3	Log.	0.0000000
$\overline{365.2563\&c.}^2$	Log.	5.1251956
$\overline{2.765765}^3$	Log.	1.3254450
	2)	6.4506406 Log. of the square of the periodic time.
		3.2253203 Log. of periodic time.

Ans., 1680 days.

PROB. 2. If the mean solar distance of Hygeia is 3.149384, what is her periodic time?

Ans., 2041.4 days.

PROB. 3. If the mean solar distance of Amphitrite is 2.546297, what is her periodic time?

Ans., 1484 days.

PROB. 4. If the periodic time of Flora is 1193 days, what is her distance from the sun?

Ans., 2.201 times the earth's solar distance.

PROB. 5. If the periodic time of Jupiter is 4332.6 days, what is his distance from the sun?

Ans., { 5.2012 times the earth's solar distance, or 494,114,000 miles.

PROB. 6 If the periodic time of Venus is 224.7 days, what is her solar distance?

Ans., 68,716,000 miles.

To find the distance of a heavenly body from the earth, when its horizontal parallax and the radius of the earth are known.

(5)

In figure 5 let S represent a heavenly body, and E the earth, SE a line drawn from the centre of the heavenly body to the centre of the earth, and SL a line drawn from the centre of the body to the surface of the earth, tangent to it at the extremity of the earth's radius, EL. Then in the right-angled triangle, SLE, right-angled at L, we have given the side LE, and also the angle LSE, the horizontal parallax of the body, (Art. 94,) to find the distance SE, which is obtained by the following proportion. Sine of the horizontal parallax (sine LSE) : the semi-diameter of the earth (LE) : : radius : the distance (SE).

PROB. 1. What is the *distance* of the sun from the earth, its horizontal parallax being 8.″6, and the earth's semi-diameter 3956.2 miles?

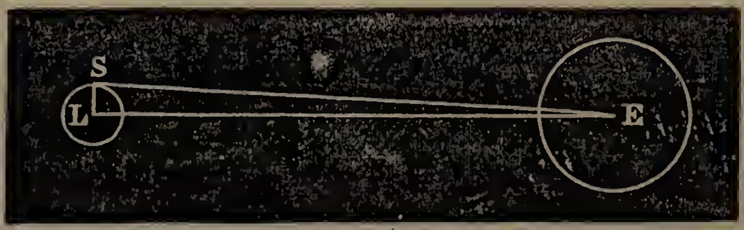
Ans., 94,886,960 miles.

PROB. 2. If the moon's horizontal parallax is 57′, and the radius of the earth 3956.2 miles, what is her *distance* from the earth?

Ans., 238,616 miles.

To find the diameter, in miles, of a heavenly body, when its apparent diameter and distance from the earth are known.

(6)



If in figure 6, S represents the heavenly body, and E the earth, and EL and ES two lines drawn from the centre of the earth to the surface and centre of the body, then as SE is a tangent, we have a right-angled triangle, SLE, in which the angle LSE is a right angle, the line LE the distance between the two bodies, and the angle LES is the apparent semi-diameter of the body. From these quantities the line SL can be found by the following proportion.

R : the distance (LE) : : the sine of the semi-diameter (sine of LES) : SL.

PROB. 1. If the mean distance of the sun from the earth is 95,298,260 miles, and its apparent semi-diameter 16′, what is the extent of his *diameter* in miles?

Ans., 887,073 miles.

PROB. 2. If the average distance of the moon from the earth is 238,650 miles, and her apparent semi-diameter 15′ 40″, what is the extent of her diameter in miles?

Ans., 2175.2 miles.

PROB. 3. If Jupiter, at his opposition, is 608,000,000 miles from the earth, and his apparent diameter is 30″, what is the extent of his *diameter* in miles.

Ans., 88,432 miles.

A movable planisphere of the heavens has been constructed by Mr. Henry Whitall, of New York, which is an excellent substitute for a celestial globe, and can be furnished at a mere fraction of the cost of the latter. A great number of important problems in astronomy can be solved by it with facility, and to one who wishes to study the starry heavens, it will be of the greatest use.

APPENDIX.

TABLE OF KNOWN ASTEROIDS,

FROM THE LATEST AUTHORITIES.

In the calculation of the solar distances the radius of the Earth's orbit is taken at 95,000,000 miles.

SYMBOL.	NAME.	SOLAR DISTANCE.	PERIODIC TIME.	BY WHOM DISCOVERED.	WHEN DISCOVERED.
		Miles.	Days		
(1)	CERES	262,764,110	1680	Piazzi, at Palermo, . . .	1801, Jan. 1.
(2)	PALLAS . . .	263,186,670	1684	Olbers, at Bremen, . . .	1802, Mar. 28.
(3)	JUNO	253,524,410	1592	Harding, at Lilienthal, .	1804, Sept. 1.
(4)	VESTA	224,327,205	1325	Olbers, at Bremen, . . .	1807, Mar. 29.
(5)	ASTRÆA . . .	244,767,500	1511	Hencke, at Driessen, . .	1845, Dec. 8.
(6)	HEBE	230,414,710	1380	Hencke, at Driessen, . .	1847, July 1.
(7)	IRIS	226,683,965	1346	Hind, at London, ...	1847, Aug. 13.
(8)	FLORA	209,131,670	1193	Hind, at London, ...	1847, Oct. 18.
(9)	METIS	226,644,350	1346	Graham, at Markree, . .	1848, Apr. 25.
(10)	HYGEIA . . .	299,190,435	2041	De Gasparis, at Naples,	1849, Apr. 12.
(11)	PARTHENOPE	232,995,860	1403	De Gasparis, at Naples,	1850, May 13.
(12)	VICTORIA, or CLIO	221,617,045	1301	Hind, at London, ...	1850, Sept. 13.
(13)	EGERIA . . .	244,684,375	1510	De Gasparis, at Naples,	1850, Nov. 2.
(14)	IRENE	245,989,960	1522	Hind, at London, ...	1851, May 20.
(15)	EUNOMIA . .	251,197,100	1570	De Gasparis, at Naples,	1851, July 29.
(16)	PSYCHE . . .	277,661,440	1825	De Gasparis, at Naples,	1852, Mar. 17.
(17)	THETIS	235,002,450	1421	Luther, at Bilk, ...	1852, Apr. 17.
(18)	MELPOMENE	218,125,700	1271	Hind, at London, ...	1852, June 24.
(19)	FORTUNA . .	231,929,960	1393	Hind, at London, ...	1852, Aug. 22.
(20)	MASSILIA . .	228,891,670	1366	Chacornac, at Marseilles,	1852, Sept. 19.
(21)	LUTETIA . . .	231,365,945	1388	Goldschmidt, at Paris, .	1852, Nov. 15.
(22)	CALLIOPE . .	237,080,005	1440	Hind, at London, ...	1852, Nov. 16.
(23)	THALIA . . .	249,738,280	1557	Hind, at London, ...	1852, Dec 15.
(24)	THEMIS . . .	299,244,965	2042	De Gasparis, at Naples,	1853, Apr. 5.
(25)	PHOCŒA . . .	228,100,700	1359	Chacornac, at Marseilles,	1853, Apr. 6.
(26)	PROSERPINE	252,327,505	1581	Luther, at Bilk, ...	1853, May 5.
(27)	EUTERPE . .	222,993,975	1314	Hind, at London, ...	1853, Nov. 8.
(28)	BELLONA . .	263,641,815	1689	Luther, at Bilk, ...	1854, Mar. 1.
(29)	AMPHITRITE	242,712,270	1492	Marth, at London, . . .	1854, Mar. 1.
(30)	URANIA . . .	224,598,905	1328	Hind, at London, ...	1854, July 22.
(31)	EUPHROSYNE	299,835,010	2048	Ferguson, at Washington,	1854, Sept. 1.
(32)	POMONA . . .	245,958,705	1522	Goldschmidt, at Paris, .	1854, Oct. 26.
(33)	POLYMNIA .	272,372,125	1773	Chacornac, at Paris, . .	1854, Oct. 28.
(34)	CIRCE	255,388,690	1610	Chacornac, at Paris, . .	1855, Apr. 15.
(35)	LEUCOTHEA	283,216,755	1880	Luther, at Bilk, ...	1855, Apr. 19.
(36)	ATALANTA .	261,126,975	1665	Goldschmidt, at Paris, .	1855, Oct. 5.
(37)	FIDES	250,981,165	1568	Luther, at Bilk, ...	1855, Oct. 5.
(38)	LEDA	260,270,075	1656	Chacornac, at Paris, . .	1856, Jan. 12.
(39)	LÆTITIA . . .	263,091,765	1683	Chacornac, at Paris, . .	1856, Feb. 8.

TABLE OF KNOWN ASTEROIDS.

SYMBOL.	NAME.	SOLAR DISTANCE.	PERIODIC TIME.	BY WHOM DISCOVERED.	WHEN DISCOVERED
		Miles.	*Days*		
(40)	HARMONIA .	215,379,060	1247	Goldschmidt, at Paris, .	1856, Mar. 31.
(41)	DAPHNE † . .	228,032,015	1358	Goldschmidt, at Paris, .	1856, May 23.
(42)	ISIS	231,219,455	1387	Pogson, at Oxford, . . .	1856, May 23.
(43)	ARIADNE . .	209,364,610	1195	Pogson, at Oxford, . . .	1857, Apr 15.
(44)	NYSA	230,886,670	1384	Goldschmidt, at Paris, .	1857, May 27.
(45)	EUGENIA . .	260,568,660	1659	Goldschmidt, at Paris, .	1857, June 27.
(46)	HESTIA . . .	241,296,960	1479	Pogson, at Oxford, . . .	1857, Aug. 16.
(47)	AGLAIA . . .	273,641,325	1786	Luther, at Bilk, ...	1857, Sept. 15.
(48)	DORIS	295,150,275	2000	Goldschmidt, at Paris, .	1857, Sept. 19.
(49)	PALES	293,180,925	1980	Goldschmidt, at Paris, .	1857, Sept. 19.
(50)	VIRGINIA . .	251,844,430	1577	Ferguson, at Washington,	1857, Oct. 4.
(51)	NEMAUSA . .	225,901,640	1339	Laurent, at Nismes, . .	1858, Jan. 22.
(52)	EUROPA . . .	294,330,710	1992	Goldschmidt, at Paris, .	1858, Feb. 4.
(53)	CALYPSO . .	248,224,930	1543	Luther, at Bilk, ...	1858, Apr. 4.
(54)	ALEXANDRA	258,811,540	1642	Goldschmidt, at Paris, .	1858, Sept. 11.
(55)	PANDORA . .	263,965,195	1692	Searle, at Albany, . . .	1858, Sept. 11.
(56)	MELETE . . .	245,428,700	1517	Goldschmidt, at Paris,	1857, Sept. 9.
(57)	MNEMOSYNE	299,942,265	2049	Luther, at Bilk,	1859, Sept. 22.
(58)	CONCORDIA	255,971,895	1615	Luther, at Bilk,	1860, Mar. 24.
(59)	OLYMPIA . .	257,714,955	1632	Chacornac, at Paris,	1860, Sept 12.
(60)	ECHO	227,203,995	1351	Ferguson, at Washington,	1860 Sept. 15.
(61)	DANAË	285,377,815	1902	Goldschmidt, at Paris,	1860, Sept. 19.
(62)	ERATO	297,430,750	2024	Foster and Lesser, at Ber-	1860, Oct. 10.
(63)	AUSONIA .	227,654,200	1355	DeGasparis, at Naples, [lin	1861, Feb. 10.
(64)	ANGELINA .	254,437,170	1601	Tempel, at Marseilles,	1861, Mar. 2.
(65)	CYBELE . . .	325,996,965	2322	Tempel, at Marseilles,	1861, Mar. 4.
(66)	MAJA	252,117,278	1579	Tuttle, at Cambridge,	1861, Apr. 9.
(67)	ASIA	229,421,200	1371	Payson, at Madras, [Mass.	1861, Apr. 17.
(68)	LETO	258,652,510	1641	Luther, at Bilk,	1861, Apr. 29.
(69)	HESPERIA . .	290,924,010	1957	Schiaparelli, at Milan,	1861, Apr. 29.
(70)	PANOPŒA . .	253,662,065	1594	Goldschmidt, at Paris,	1861, May 5.
(71)	FERONIA . .	203,783,740	1148	Peters, at Clinton, N. Y.,	1861, May
(72)	NIOBE	261,841,470	1671	Luther, at Bilk, [Mass.,	1861, Aug. 13.
(73)	CLYTIA . . .			Tuttle, at Cambridge,	1862, Apr. 8.
(74)	GALATEA . .	244,645,135	1509	Tempel, at Marseilles,	1862, Aug. 29.
(75)	Not named	251,121,955	1570	Peters, at Clinton, [gen,	1862, Sept. 22.
(76)	FREYA	302,955,000	2080	M. d'Arrest, at Copenha-	1862, Oct. 21.
(77)				Peters, at Clinton,	1862, Nov. 12.
(78)	DIANA	262,418,500	1677	Luther, at Bilk,	1863, Mar. 15.
(79)	EURYNOME .	232,294,000	1397	Watson, at Ann Arbor,	1863, Sept. 14.

THE EARTH'S RING.

At Providence, R. I., on the 18th of August, 1855, the Rev. George Jones, U. S. N., read before the American Association for the Advancement of Science, a very valuable paper on the *Zodiacal Light*, founded upon his own observations. These were made by Mr. Jones, during his late cruise in the United States steam-frigate Mississippi, and extended in latitude from 41° N. Lat. to 52° S. Lat. No observations on the Zodiacal Light were ever before made *south of the equator*. Mr. Jones exhibited to the Association two thick quarto volumes, containing 331 observations, each observation being accompanied by a drawing exhibiting the *form*, and the *position* of the *Zodiacal Light* among the stars, at the time of the observation.

These observations have revealed many new and surprising facts, respecting the *Zodiacal Light*, and the learned observer, from a careful study of them all, arrived at the conclusion that the *Zodiacal Light* is a *luminous ring which encircles the Earth*, as the ring of Saturn surrounds that planet.

Prof. Pierce, of Harvard College, spoke in the highest terms of this communication, and remarked, "that he had enjoyed the privilege of examining Mr. Jones' observations and drawings, and that he fully concurred with him in his theory—from them only one inference could be drawn, viz., that the *Zodiacal Light* was the *Earth's Ring*."